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Prepared for

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SECOND SYMPOSIUM ON FUGITIVE EMISSIONS: MEASUREMENT AND CONTROL

(May 1977, Houston, Texas)

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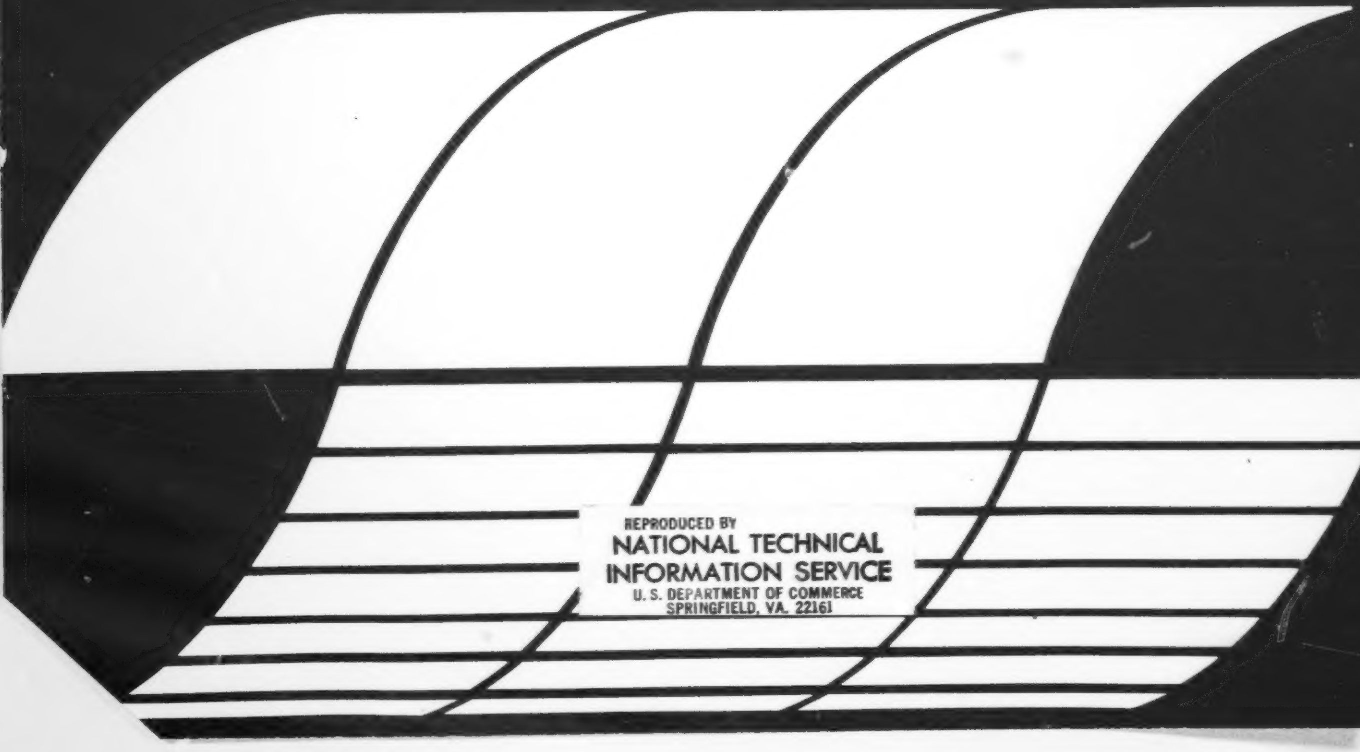
Program Report



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16. ABSTRACT

The proceedings are a compilation of technical papers prepared for presentation at the Second Symposium on Fugitive Emissions, May 23-25, 1977, Houston, Texas. The papers discuss the scope and impact of fugitive emissions (non-point sources) and present techniques which have been used ~~the~~ to measure these emissions. Fugitive emissions control technologies are also discussed.

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Prepared for

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Washington, D.C. 20460

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FOREWORD

The technical papers included in this volume were prepared for presentation at the Second Symposium on "Fugitive Emissions: Measurement and Control" on May 23-25, 1977 at Houston, Texas.

The Symposium was sponsored jointly by the Environmental Protection Agency's Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina and the Air Pollution Control Association's TS-5.2 Committee on Fugitive Emissions. The objectives of the Symposium were to disseminate information relative to the impact of fugitive emissions from industrial processes on our atmosphere and ground waters, and to bring together concerned representatives of industrial, research-oriented and governmental organizations to consider strategies for fugitive emission control.

Dr. Robert M. Statnick of the Industrial Environmental Research Laboratory, Environmental Protection Agency, Research Triangle Park, North Carolina, was the Project Officer and General Chairman of the Symposium.

Joanne King of TRC - The Research Corporation of New England, Wethersfield, Connecticut, was the Symposium Coordinator and Compiler of the Proceedings.

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OVERVIEW OF FUGITIVE EMISSIONS

By

Gary McCutchen

Emission Standards and Engineering Division
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ABSTRACT

OVERVIEW OF FUGITIVE EMISSIONS

New information on particulate and hydrocarbon fugitive emission quantities has confirmed their significance. Near sources, fugitive emission impact on air quality predominates, especially if stack emissions are reasonably well-controlled. The effect of including fugitive emissions in SIP revisions and New Source Review and emission offset determinations is expected to be great, but the implications of this policy have not been fully realized. Opacity measurements have the potential to substitute for difficult mass emission tests.

OVERVIEW OF FUGITIVE EMISSIONS

Gary McCutchen

At last year's first fugitive emissions symposium, several speakers indicated that the quantification and regulation of these emissions would likely require a major control agency effort during the next five years. Looking back over developments in the past year, I think you will agree that these predictions, if anything, understated the attention fugitive sources are receiving.

Two developments have spurred control agency efforts: (a) non-attainment of National Ambient Air Quality Standards (NAAQS) in many Air Quality Control Regions (AQCR) and (b) an accumulation of additional information indicating that fugitive emissions and dust are significant in terms of both mass and ambient air impact. These and related developments are the topic of this paper.

Definitions(1)

The term fugitive emissions as used in this paper includes either gaseous or particulate emissions from industry-related operations that escape to the atmosphere without passing through a primary exhaust system. This includes emissions from loading, unloading, and transport of materials; storage piles; and roads and open areas within the plant boundaries. As distinguished from fugitive emissions, fugitive dust includes natural dusts (e.g., dust storms), and agricultural and other non-industry activities (e.g., unpaved roads, urban street dust, commercial construction sites). Fugitive sources refers to both fugitive dust and fugitive emission sources.

Non-Attainment

Of the 313 AQCRs and State portions of interstate AQCRs, 245 have not attained NAAQS for one or more criteria pollutants.(2) This has resulted in 246 pollutant-specific calls for attainment/maintenance revisions to SIPs and 25 pollutant-specific calls for maintenance revisions only (Table 1). The majority of the plan revisions are for oxidants and total suspended particulate (TSP). The large number of oxidant revisions is partly a result of calls for statewide revisions in Regions II, III, and V. Transport problems necessitate hydrocarbon controls over wide geographic areas to attain the oxidant standard.

The second largest number of SIP calls for revision were made for TSP. Additional point source control and fugitive dust control were the measures most frequently recommended. Fugitive dust control is a new program for most control agencies, including EPA, but a comprehensive EPA policy paper is now undergoing final internal review.(3) Fugitive emissions, especially particulate matter from point sources, are being closely studied in areas where more stringent control measures are required. Nearly 70 percent of all Regional Office contract assistance requests concern particulate sources,(4) and these studies concentrate on fugitive sources. As an example, GCA inspected a ferrochrome plant in Charleston, South Carolina, for Region IV.(5) Their draft final report includes estimates that particulate emissions total 92 pounds per hour, of which only eight pounds per hour is emitted from control device stacks. The remaining 84 pounds per hour are fugitive emissions.

Fugitive Emission Measurement

Selected fugitive emission estimates are summarized in Table 2. In many cases they constitute a large percentage of total emissions from a well-controlled plant. Fugitive emissions represent 75 percent of total vinyl chloride emissions from a polyvinyl chloride (PVC) plant meeting NESHAPS (which require an estimated 90 percent control of fugitive and 99 percent control of stack emissions).(6) The surprising thing is that fugitive emissions can also be significant at uncontrolled plants, e.g., 40 percent of total vinyl chloride emissions from uncontrolled PVC manufacture. Emissions from some fugitive sources are astonishingly large. Fugitive hydrocarbon emissions from cutback asphalts are equivalent to 2.3 percent of total national hydrocarbon emissions: 742,000 tons in 1975.(7)

Air Quality Impact

Previous air quality studies have indicated that fugitive emission ambient air concentrations around a plant are greatest at the fenceline and decrease rapidly with distance from the source. High fenceline concentrations are expected because fugitive emissions usually occur (a) near the ground with (b) little or no thermal lift. They thus reach ground level with much less plume dilution than do stack emissions. Since fugitive emissions don't go through a control device, faster-settling coarse particles are expected to comprise a larger portion of the fugitive emission mass. The result would be a rapid decrease in fugitive emission ambient air concentrations downwind of the source as the large particles settle out. Now, as a result of efforts to model ambient concentrations near stationary sources of lead, there are strong indications that fugitive emission impacts can extent several kilometers beyond plant fencelines. Even more unexpected is the possibility that fugitive emissions from tall structures may not reach ground level until well beyond the fenceline. Ambient air monitors located at property lines wouldn't measure the impact such emissions would have further downwind.

The original NAAQS strategies established in the early 1970's were concerned almost exclusively with stack emissions. There wasn't even enough fugitive emission information available to assess the importance of such sources, although Federal guidelines (40 CFR 51, Appendix B) did recommend a "reasonable precautions" approach, including general techniques for minimizing both fugitive emissions and fugitive dust. The lead NAAQS strategies being developed, in contrast, reflect an increased awareness of fugitive emissions as an ambient air problem.

As a part of the lead NAAQS development, EPA is attempting to determine lead ambient air concentrations in the vicinity of lead sources using diffusion modeling. The model used to estimate air quality around lead sources is the only well-documented one able to accommodate deposition phenomena. This is the Atmospheric Transport and Diffusion Model (ATM) developed at Oak Ridge National Laboratory. It is designed to consider both deposition and gravitational settling, so requires particle size data in addition to the usual modeling parameters. For the first time, fugitive as well as stack emissions from point sources can be modeled.

Using ATM, EPA identified three stationary sources of lead around which 90-day average ambient air lead concentrations could reach in excess of five micrograms per cubic meter ($\mu g/m^3$) despite good stack air pollution control. These sources are (a) primary lead smelters, (b) primary copper smelters, and (c) tetraethyl lead (TEL) plants.(8) For the smelters, preliminary results show that fugitive emissions contribute more to ambient air concentrations than do stack emissions, as Figure 1 shows. The solid lines in Figure 1 represent total emissions impact in terms of "worst case" 90-day average ambient air concentrations. Stack emissions impact is shown by a dashed line for the lead smelter; for the copper smelter, the 90-day average stack contribution is essentially zero. Shaded areas represent the fugitive emissions impact.

The preliminary parameters used to model the lead and copper smelter ambient air impacts are summarized in Tables 3 and 4, respectively. In terms of size, the copper smelter produces 365 tons of copper per day, while the lead smelter produces 185 tons of lead per day. Lead emissions from the copper smelter total 3.6 grams per second, half of it fugitive. The lead smelter emits 2.73 grams lead per second, only 15 percent of it fugitive. Stack emissions for both smelters represent good control efficiency, while fugitive emissions are assumed to be uncontrolled.

The striking differences between the total concentration curves in Figure 1 are a result of emission rates and assumed release height. At the lead smelter, fugitive emissions are released near the ground. Ambient air impact near the plant is large, but decreases rapidly with distance. Emissions from the reverberatory furnace building keep concentrations fairly high from about one kilometer (km) to nearly 3 km. This exponential decay curve is typical of fugitive emissions released near ground level.

Less typical is the concentration curve for the copper smelter. Fugitive emissions are, in this case, released 30 meters above ground; their full impact occurs nearly 2 km downwind of the plant. The effect is characteristic of a short stack. Note that the lead ambient concentration is above 15 $\mu g/m^3$ even 5 km from the plant, a result of fugitive lead emission rates four times that of the lead smelter.

These results are, of course, preliminary. Not all fugitive emission sources at these plants are included and some of the modeling parameters may change, but it is clear that EPA needs to take fugitive sources into account.

A less complex program for modeling short-term (24-hour average) ambient concentrations resulting from stack and fugitive particulate emissions will soon be available from EPA. It is a revision of an existing point source model, and is being prepared by Phil Youngblood, MDAD, EPA, in conjunction with a document on industrial process fugitive emissions being prepared by PEDCo Environmental for Gil Wood, ESED, EPA.

The effect of fugitive emissions from numerous sources on urban air quality is even more difficult to determine that the effect of a single source. In one analysis, the long-term contribution of fugitive dust and emissions to hi-vol sampler readings was determined using data from seven U.S. urban areas.(10) Near industries, fugitive sources added 15 micrograms per cubic meter ($\mu g/m^3$) to the central city total suspected particulate (TSP) concentrations and 23 $\mu g/m^3$ in suburban areas. This is probably a combination of industry-related fugitive emissions, reentrained street dust, and motor vehicle emissions. In commercial areas, fugitive sources added 12 and 20 $\mu g/m^3$ at urban and suburban sites, respectively. These values are only slightly lower than those for industrial areas, but the difference could represent the direct impact of industrial fugitive emissions.

NSPS and NESHAPS

Realization of the difficulties in attainment of NAAQS caused by fugitive emissions has also strengthened concern that new facilities could add to the problem. Some new source performance standards (NSPS) require fugitive emission control (Table 5), but there is now a much greater emphasis on the problem. This shift in program emphasis is most apparent in EPA's oxidant-related hydrocarbon studies. Within the past year, Emission Standards and Engineering Division (ESED) program resources shifted from nearly no hydrocarbon work to a commitment of over 50 percent of ESED resources to this task. Many sources, from oil field through refining and organic chemical production to end use, are under study. Present plans are to first issue guideline documents for States to use in revising SIP's, then develop NSPS. Some of these studies are already providing data. Emissions from miscellaneous refinery sources (valves, pumps, etc.) make up significant fractions of total refinery hydrocarbon emissions. The first five guidance documents, on different coating operations (auto assembly and coil, can, fabric, and paper coating), are being issued for use by States with oxidant problems.

These studies also illustrate the difficult task emission testing often poses. Efforts to quantify emissions from floating roof storage vessels, in four separate studies, have cost $700,000;(11) another $500,000 to $750,000 commitment is expected over the next two years. Nearly all of this is industry, rather than EPA, funded. The cost of testing is one reason why so little is known about fugitive emission quantities, and why control agencies (and, usually, industry) prefer specifying equipment and/or operating procedures to field testing.

Controlling especially dangerous pollutants, national emission standards for hazardous air pollutants (NESHAPS) have historically reflected greater concern for fugitive emissions than have NSPS. Asbestos regulations, which already require control measures for storage piles, are being expanded or studied for decorative sprays, quarries, and paving roads with asbestos-containing gravel (asbestos tailings for roadway use are already prohibited). The vinyl chloride NESHAPS includes requirements for 90 percent control of nine different fugitive emission sources at manufacturing plants.(6) Finally, the need for and feasibility of a NESHAPS for benzene emissions from coke ovens and other sources is being studied.

New Source Review

Many stationary source New Source Review (NSR) policies, including prevention of significant deterioration and emission offsets, are so new that their full implications have not yet been realized, but every interpretation to date considers fugitive emissions a part of total emissions.(3) The issues resulting from this decision are far too complex to be discussed in this overview, so only two brief examples will be given:

Major sources - only "major" new sources, in terms of tons per year of allowable emissions, are affected by most NSR procedures. Owners and operators should be aware that this includes allowable fugitive, as well as stack, emissions.

Fugitive source offsets - The quantity of new emissions that must be offset in non-attainment areas includes fugitive emissions; credit, of course, is also given for reducing fugitive sources.

Fugitive Emission Studies

Probably the most studied of any source category, iron and steel mills contain numerous fugitive pollution sources. There are over 20 EPA-funded studies of the iron and steel industry underway, and over half concern fugitive air pollution source evaluation. Attention has been focused on these sources because 80 percent of iron and steel mill air pollution problems are fugitive emission related.(12) Coke oven coal and coke handling, door and topside leaks, and pushing and quenching emissions can all be classified as fugitive, as can storage pile, roof monitor, and transportation-related emissions. The studies have resulted in improved emission factors for many difficult-to-quantify steel mill sources. Quench towers and coke oven emissions have been source sampled. Factors for paved and unpaved roads, storage piles, and material handling have been developed for heavy-duty vehicles and specific materials. Some of these estimates are given in Table 2; the others appear in a special fugitive process emissions study.

The primary purpose of the special study is to produce a guideline document for the States to use in estimating fugitive emission rates and ambient air impacts for SIP revisions, NSR review, and other air management programs.(13) The document, which is based on a review of the literature, comprises approximately 400 pages of information on fugitive particulate sources and should be distributed this month. Factors from the document are already being used to evaluate fugitive source emission rates and emission reduction capabilities.

Most of the document consists of information on various source categories, including (a) a description of each process, (b) fugitive emission rates and characteristics, (c) example plant emission inventories, and (d) control techniques. Coverage of iron and steel, lime, primary lead, and materials extraction (hard and soft rock and earthy materials) source categories is fairly good. Existing information on other sources is much less satisfactory.

In addition to emission rates, the document discusses capture and control options and costs. Impact on air quality is examined, and the 24-hour model described earlier will be tailored for use with the emission information provided. Finally, strategies for integrating this information into the SIPs is outlined.

Regulatory Aspects

At the last count, 17 States lacked regulations pertaining to fugitive emissions.(14) The other States have one or more of three general types of regulations: (a) non-specific nuisance, (b) quantitative property line, and (c) specific control measures.(13) The most common is the nuisance, or "reasonable precautions" type. It is usually more effective in dealing with diverse sources of fugitive dust, but some States, like Vermont and West Virginia, have modified such regulations to effectively apply to control of fugitive emissions.

Property line regulations take many forms. Texas, for example, has successfully applied an upwind-downwind method, limiting the difference in measured ambient concentrations. Illinois and Missouri, in addition, consider particulate size.

Colorado is considered the best example of a State which requires implementation of specific control techniques for specific fugitive dust and emission sources, such as unpaved roads, explosives detonation, open mining, and unenclosed operations. Many other States specify control techniques for specific processes, such as Alabama's coke oven regulation.(13)

There are as many variations as there are States, but the primary regulatory and enforcement tool continues to be opacity. The development of detailed coke oven opacity reading procedures over the past year has helped establish a firm methodology for non-stack opacity observations.(15) Similar techniques may prove applicable for other difficult-to-read fugitive sources.

Another development is the slow but steady correlation of optical density with emission mass for specific sources. Sources for which an opacity/mass relationship exists include asphalt concrete plants, sludge incineration, catalytic cracking unit regenerators (petroleum refineries), secondary brass and bronze and lead smelters, and coal-fired power plants.

One unsatisfactory attempt has been made to obtain a similar correlation for oil-fired power plant emissions.

These studies are only for one stack at one plant over a few days' operation. A much broader data base is needed before general correlations for each source category can be attempted, but this is a start. If successful, such efforts may eventually lead to optical measurement of fugitive plumes, thereby avoiding difficult and expensive mass measurement techniques.

Summary

New information on particulate and hydrocarbon fugitive emission quantities has confirmed their significance. Near sources, fugitive emission impact on air quality predominates, especially if stack emissions are reasonably well-controlled. The effect of including fugitive emissions in SIP revisions and New Source Review and emission offset determinations is expected to be great, but the implications of this policy have not been fully realized. Opacity measurements have the potential to substitute for difficult mass emission tests.

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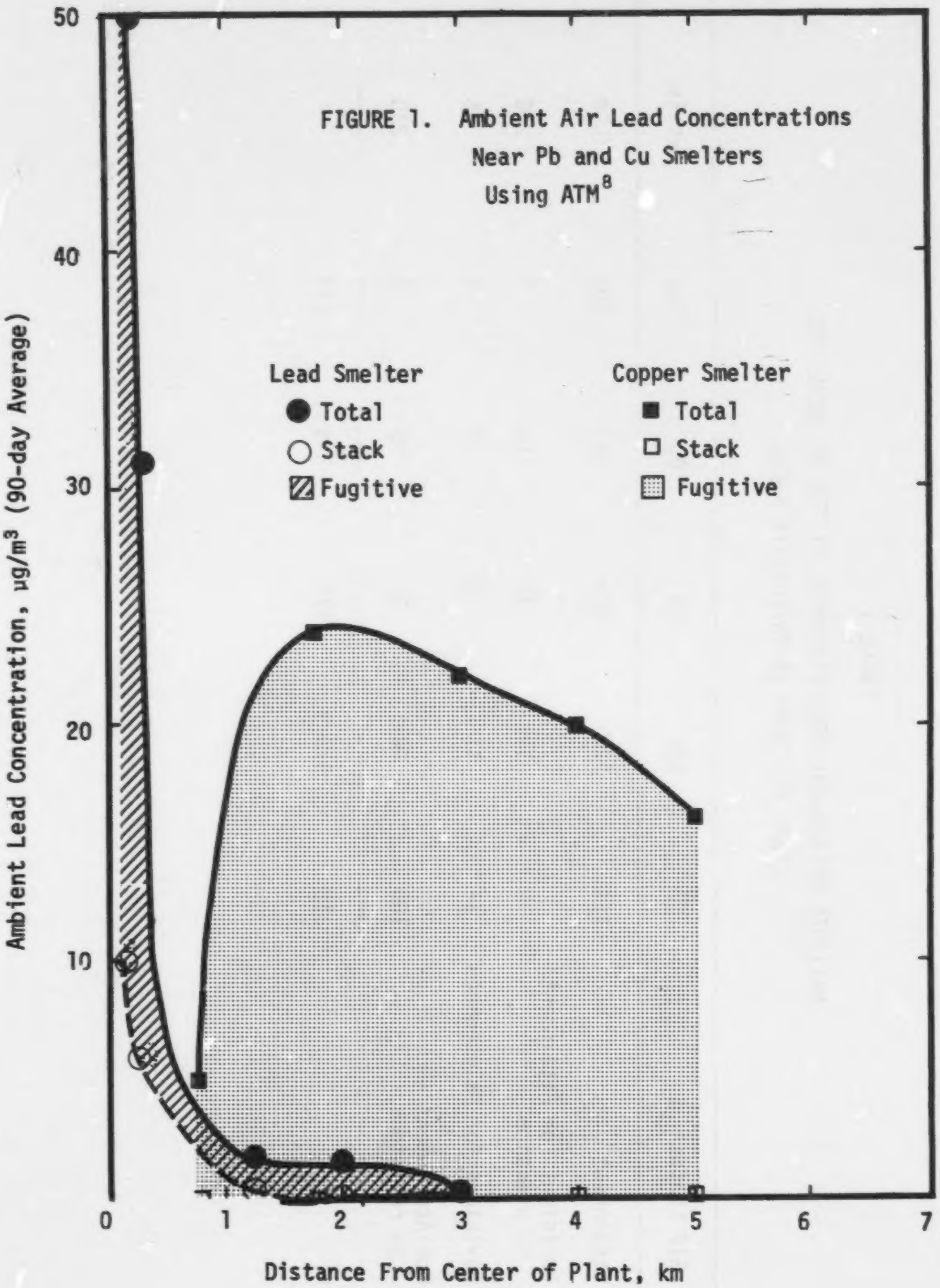

FIGURE 1. Ambient Air Lead Concentrations Near Pb and Cu Smelters Using ATM[8]

TABLE 1

NATIONAL ATTAINMENT/NON-ATTAINMENT STATUS OF AQCRs AND STATE PORTIONS OF INTERSTATE AQCRs

SIP Status	TSP	SO_2	CO	O_x	NO_x	Totals
Attainment	124	256	233	143	308	1064
Revisions for Attainment/ Maintenance	78	12	41	114	1	246
Revisions for Maintenance	11	11	2	0	1	25
Non-Attainment - no revisions	100	34	37	56	3	230
	313	313	313	313	313	

TABLE 2

FUGITIVE/STACK EMISSION ESTIMATES

Sources	Fugitive Emissions	Well-Controlled Stack Emissions	Ratio: Fug./Stack
Primary Lead Smelter[a]			
Reverberatory furnace	0.35 gm Pb/sec	0.27 gm Pb/sec	1.30
Blast furnace	0.02 "	0.38 "	0.05
Sintering	0.03 "	1.65 "	0.02
Phosphate Fertilizer Plant			
WPPA, SPA, DAP, & TSP	N/A	0.29 lb F/ton P_2O_5 equiv.[b]	1.69
Pond and TSP storage	0.49 lb F/ton P_2O_5 equiv.[c]	N/A	
Ferroalloy Production[d]			
1975 actual emissions	15,400 tons PT/yr	113,846 tons PT/yr	0.13
1975 emissions if SIPs met	15,400 tons PT/yr	4,650 tons PT/yr	3.31
Cement Plant[e]	14.64 g/sec	49.26 g/sec	0.30
Iron and Steel Mills[f]			
BOF - open hood	0.5 lb/ton product	0.29 lb/ton product	1.72
- closed hood	0.5 "	0.02 "	25
EAF - carbon steel	3 "	1.35 "	2.22
- alloy steel	1.5 "	.675 "	2.22
Sintering	0.7 "	2.6 "	0.27
Open hearth	0.29 "	0.35 "	0.83
Scarfing	0.011 "	0.015 "	0.73
Windblown[g]	5 lb/ton steel produced	N/A	N/A

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TABLE 2 (Cont.)

FUGITIVE/STACK EMISSION ESTIMATES

Footnotes:

[a] Data compiled by Mark Scruggs, MDAD, OAQPS, EPA, from various sources.

[b] Total NSPS emission limitation for the sources listed.

[c] TSP storage (.05 lb/ton) is NSPS limit for 1500 ton/4 day storage; pond emissions derived from data presented by W.R. King at last year's symposium. Assumed a 125 acre pond corresponding to 500 TPD production, using square root of pond area ratio to scale up from 100 acre pond emissions of 0.39 lb/ton P_2O_5: $\sqrt{125/100} \times .39 = .44$ lb/ton P_2O_5.

[d] Conversation with Lance Granger, MRI, April 1, 1977.

[e] Example from draft Control Program Guideline for Industrial Process Fugitive Particulate Emissions, Gilbert Wood, OAQPS, EPA Project Officer.

[f] Preliminary emission factors from various sources, compiled by Reid Iversen, ESED, OAQPS, EPA.

[g] Preliminary average emissions from roads, storage piles, and open areas. Based on a study conducted by MRI for EPA. Robert Hendricks, ORD, EPA, Project Officer.

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TABLE 3

CHARACTERISTICS FOR A HYPOTHETICAL 185 TON/DAY PRIMARY LEAD SMELTER(8)

Source	Lead Emission Rate gm/s	Control Efficiency %	Stack Height** m	Stack Diameter m	Stack Gas Velocity m/s	Stack Gas Temperature °K	Area of Building m^2
Sinter Machine Stack	1.65	99	128	2.9	14.6	389	NA
Blast Furnace Stack	0.38	99	38	4.1	2.4	329	NA
Reverberatory Furnace Stack	0.27	94	38	4.1	2.4	329	NA
Fugitive Emissions From Sinter Bldg.	0.03	0	12	NA	NA	290	1290
Fugitive Emissions From Blast Furnace Building	0.02	0	14	NA	NA	290	1390
Fugitive Emissions From Reverberatory Building	0.35	0	17	NA	NA	290	770
Fugitive Emissions From Zinc Fuming Area	0.01	0	18	NA	NA	290	430
Fugitive Emissions From Zinc Furnace Building	0.02	0	15	NA	NA	290	310

**The stack height for fugitive emissions represents the average height of release

NA - Not Applicable

TABLE 4

CHARACTERISTICS FOR A HYPOTHETICAL 365 TON/DAY COPPER SMELTING PLANT(8)

	Lead Emission Rate gm/s	Control Efficiency %	Stack Height** m	Stack Diameter m	Stack Gas Velocity m/s	Stack Gas Tempera-ture °K	Area of Building m^2
Roaster Stack	0.62	97	166	6.7	10.4	480	NA
Smelter Stack	0.71	94	166	6.7	10.4	480	NA
Converter Stack	0.44	98	172	5.5	7.6	464	NA
Fugitive Emissions From Roasting	0.13	0	30	NA	NA	300	1800
Fugitive Emissions From Smelting	0.50	0	30	NA	NA	300	5100
Fugitive Emissions From Converters	1.20	0	30	NA	NA	300	2100

**The stack height for fugitive emissions represents the average height of release.

NA = Not Applicable.

TABLE 5

NSPS and NESHAPS FUGITIVE EMISSION REGULATIONS

Source Category	Type of Standard	Emissions Limited To	Pollutant
Portland Cement	Visible emissions	10% opacity	Particulate
Asphalt Concrete Plants	Visible emissions	20% opacity	Particulate
Storage Vessels for Petroleum Liquids (>40,000 gallons)	Equipment	N/A	HC
Secondary Lead Smelters (pot furnaces)	Visible emissions	10% opacity	Particulate
Secondary Brass & Bronze (blast & electric furnaces)	Visible emissions	10% opacity	Particulate
Iron and Steel Plants Electric Arc Furnace Shop	Visible emissions	Furnace: 10% opacity except: 20% during charging 40% during tapping Dust handling system: 10% opacity	Particulate
Primary Aluminum Reduction	Mass and visible emissions	Mass: 2 lb/ton product Opacity: 10% from potroom 20% from bake plant	Fluorides Particulate Particulate
Phosphate Fertilizer Plants (GTSP storage)	Mass emissions	0.25 g F/hr/metric ton equiv. P_2O_5 stored	Fluorides
Coal Preparation Plants	Visible emissions	20% opacity	Particulate
Ferroalloy Production (dust-handling system)	Visible emissions	10% opacity	Particulate
Asbestos Sources	Equipment/operating standards	N/A	Asbestos

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TABLE 5 (Cont.)

NSPS and NESHAPS FUGITIVE EMISSION REGULATIONS

Source Category	Type of Standard	Emissions Limited To	Pollutant
Beryllium Processors/Users			
Rocket Motor Firing	Ambient concentration	75 μg-min/m^3 over specified time period	Beryllium
Other Sources	Ambient concentration	0.1 μg/m^3, 30-day avg.	Beryllium
Chlor-Alkali Plants	Mass emissions	1300 g Hg/day from cellroom	Mercury
Ethylene Dichloride, Vinyl Chloride, and Polyvinyl Chloride Plants	Mass and equipment/ operating standards	Generally, 10 ppm or equivalent	Vinyl Chloride

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THE ROLE OF FUGITIVE EMISSION FACTORS IN MEETING NATIONAL AMBIENT AIR QUALITY STANDARDS

By

James H. Southerland and Charles C. Masser

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Office of Air Quality Planning and Standards
Monitoring and Data Analysis Division
Air Management Technology Branch

Abstract

Studies have shown the local and regional impact of fugitive dust and emissions on air quality. These studies also explain the basis for conclusions that such sources must be considered in developing action strategies to meet the National Ambient Air Quality Standards. A perspective illustrating the impact of fugitive sources of particulate and organics being omitted in base year State Implementation Plan (SIP) inventories is given. The status and role of emission factors useful in preparation of revised SIP's is presented with a brief summary of the major data needs particularly in the context of availability and applicability for generalized factors to be utilized in AP-42, Compilation of Air Pollutant Emission Factors. Plans to fill identified data gaps are presented with a call for assistance to the technical community in meeting the objective of making state of the art emission factors available to the State and local agencies who rely upon them as an integral part of their air resource management programs.

THE ROLE OF FUGITIVE EMISSION FACTORS IN MEETING NATIONAL AMBIENT AIR QUALITY STANDARDS

By

James H. Southerland and Charles C. Masser

Background

The Clean Air Act[1], as amended in 1970, provides that EPA develop air quality criteria, adopt National Ambient Air Quality Standards (NAAQS) for major air pollutants, define Air Quality Control Regions (AQCR's) (i.e., areas of similar air pollution characteristics), and provides for a joint Federal-State control program to ensure that the air quality in the various AQCR's throughout the country attains and maintains the NAAQS. The Act also provides for State Implementation Plans (SIP's) to be prepared by the States and approved by EPA. These plans present each State's intended course of action to implement the national standards within the periods specified in the Act - 3 years after approval for attaining the primary or health-related standards and a "reasonable time" for attaining the more stringent (welfare-related) secondary standards.

In April 1971, EPA promulgated NAAQS for five major pollutants for which air quality criteria has been developed. These five pollutants were total suspended particulates (TSP), sulfur oxides, nitrogen dioxide, carbon monoxide, and photochemical oxidants. A non-methane hydrocarbon standard was promulgated as a guide only for States to use in developing plans to meet the oxidant standard. Subsequently in early 1972, the States prepared and submitted implementation plans that in most cases were designed to attain and maintain standards by mid-1975.

Progress and Problems

The bulk of the provisions of the SIP's relating to TSP control (which is of particular interest to us at this point) were approved by EPA on May 31, 1972. Thus, under the timetable provided by the Act, the date of May 31, 1975[2] became the scheduled date for most AQCR's to attain the primary standard for TSP. A general improvement in ambient air quality with respect to total suspended particulate is continuing at the rate of 3 to 4 percent per year based upon data from nearly 1800 sites.[3] This improvement is shown graphically in Figure 1. The present rate of progress, however, may not be sustained since fewer traditional sources remain to be controlled and since fugitive dust, fugitive process emissions, and re-entrained urban particulates are more difficult to control. Approximately 30 percent of the nation's population is still living in areas above the long-term primary annual particulate standard.

On July 1, 1976, calls for State Implementation Plan (SIP) revisions were made that require States to adopt new regulations for such areas where problems exist. Failure to attain the national ambient air quality standards for particulate matter in numerous urban areas as reflected by this call for SIP revisions has resulted in a re-examination of the urban particulate problem. Basically, the particulate control strategy developed as part of the original SIP's included an analysis of the contribution of conventional point and area sources without much consideration of other less conventional sources of particulate. That these sources were not considered

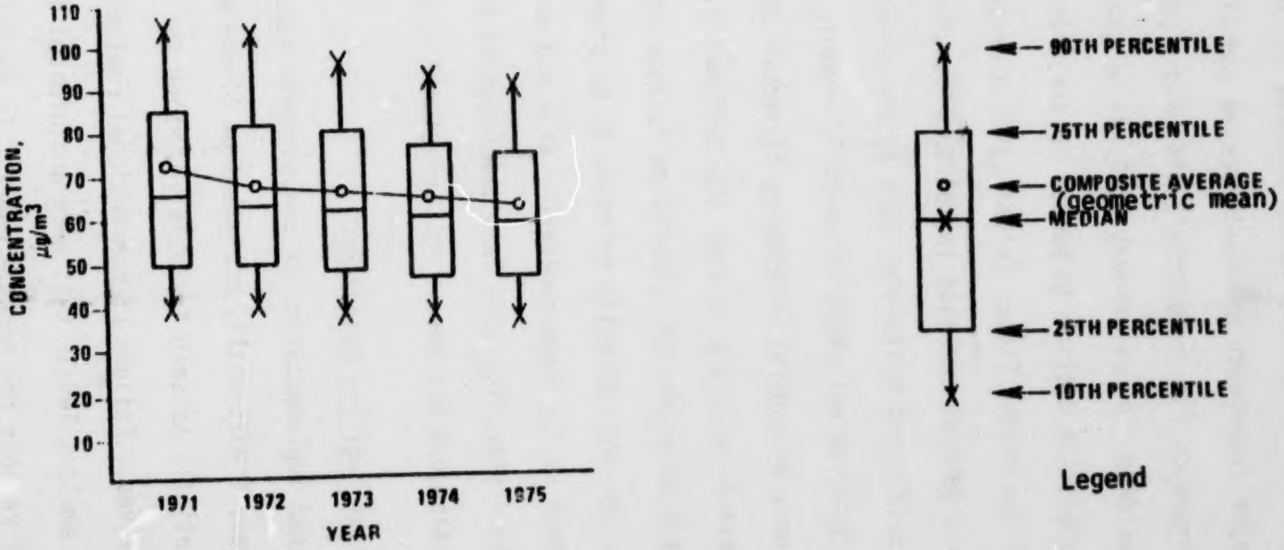

Figure 1. Trends of annual mean total suspended particulate concentrations from 1971 to 1975 at 1792 sampling sites.[3]

was due in part to the fact that no emission factors were available. It now appears that previously "neglected" sources of fugitive dust and emissions are of major importance and must receive additional attention.

Volatile organics ("hydrocarbons") and oxides of nitrogen are precursors of oxidant. A preliminary analysis of short-term trends (1973-1975)[3] suggests a decline in summer oxidant/ozone violations in the eastern part of the United States (eight sites decreasing and three sites increasing) and a general increase in metropolitan Denver. There are too few sites with sufficient historical data to characterize trends adequately, but control of fugitive emissions of volatile organics is believed to be a necessary component of control strategies to reduce oxidant precursor levels to the extent necessary to meet the national oxidant standard. Generally fugitive emissions of criteria pollutants other than particulate and hydrocarbons are not currently believed to be significant, but there are exceptions such as SO_2 from smelters. With the promulgation of a lead standard later this year, fugitive lead emissions no doubt will also receive additional attention and the demand for emission factors will increase.

Need for Control of Fugitive Emissions

With increased implementation of conventional stack controls on stationary sources, traditionally estimated particulate emissions have decreased substantially as seen in Table 1[3], which for the most part does not include fugitives. Failure of conventional control efforts to provide the decreases in ambient levels that were anticipated have lead to a re-examination of reasons for nonattainment. In so doing, various agencies have noted the apparent significant air quality impact of fugitive emission

Table 1. Summary of National Emissions Estimates, 1970-1975[3]

(10^6 tons/yr)

Year	Particulates	SO_x	NO_x	HC	CO
1970	26.8	34.2	22.7	33.9	113.7
1971	24.9	32.3	23.4	33.3	113.7
1972	23.4	26.7	24.6	34.1	115.8
1973	21.9	35.6	25.7	34.0	111.5
1974	20.3	34.1	25.0	32.9	103.3
1975	18.0	32.9	24.4	30.9	96.2

*These figures generally do not include fugitive process emissions or fugitive dust sources. Some initial estimates have indicated that they often appear to have a greater effect on air quality in the immediate vicinity of a source than do controlled (and sometimes uncontrolled) stack emissions. One recent study of 14 cities[4] found that these unconventional sources contribute 25 to 35 micrograms per cubic meter to the citywide TSP levels, thereby preventing the attainment of standards.

At this time, it may be necessary to define the differences between and discuss pertinent facts concerning two separate but, in some cases, strikingly similar air pollution problems (i.e., fugitive process emissions and fugitive dust emissions). When using the term fugitive (process) emissions, we are referring to both gaseous and particulate emissions that result from industrial-related operations and which escape to the atmosphere through windows, doors, vents, etc. but not through a primary exhaust system such as a stack, flue, or control system. Fugitive process emissions may result from metallurgical furnace operations, materials handling, transfer and storage operations where emissions escape to the atmosphere. Fugitive emissions, by their very nature, generally occur at or near ground level and tend to remain at low levels where the localized impact on air quality in the area is greatest.

Fugitive dust emissions, on the other hand, are generally related to natural or man-associated dusts (particulate only) that become airborne due to the forces of wind, man's activity, or both. Fugitive dust emissions may include windblown and traffic-generated particulate matter from unpaved dirt roads, tilled farm lands, exposed surface areas at construction sites, etc. Naturally "erodible" dusts that become airborne are also generally included in the fugitive dust definition.

While measurements of fugitive dust and fugitive emissions (both particulate and gaseous) have proven difficult, approximations have been made which indicate that such sources may comprise a significant portion of nationwide emissions and localized sources impacting upon local air quality are sufficiently widespread to be of national significance. Thus, if the NAAQS (for TSP and oxidant in particular) are to be attained nationwide, serious attention must be paid to the role which fugitive dust and fugitive process emissions play.

The Role and Uses of AP-42 Emission Factors

In the assessment of community air pollution, there is a critical need for accurate data on the quantity and characteristics of emissions from the numerous sources that contribute to the problem. The large number of individual sources and the diversity of source types generally make conducting field measurements of emissions on a source-by-source basis at each point of release impractical. The most feasible method of determining pollutant emissions for a given community is to make generalized estimates of typical emissions from each of the source types. Emissions from all sources, as totaled and tabulated in an emission inventory, provide a valuable technique for assessing the character of the local problems and for development of workable, reasonable, and cost-effective control strategies. They, along with ambient data, constitute the basic "corner stones" of a viable air pollution control and air resource management program.

One of the most useful (and critical) tools for estimating typical emissions for an emission inventory is the emission factor. This is an estimate of the rate at which a pollutant is released to the atmosphere from a specific source category as a result of some activity such as combustion or industrial production divided by the level of the activity. In other words, the emission factor relates the quantity of pollutants emitted to some measurable surrogate indicator (activity level) such as production capacity, quantity of fuel burned, or vehicle miles traveled.

EPA has collected and has a continuing program underway to develop and update such emission factors in published form; "Compilation of Air Pollutant Emission Factors,"[5] commonly referred to as AP-42. This document has become an internationally accepted primary reference that is used by State and local agency officials and others in their emission inventory efforts and related activities which require estimation of emissions (such as preparation of environmental impact statements).

The emission factors presented in AP-42 have been developed using a wide spectrum of techniques. A program to periodically update and revise this document has been in effect and is continuing. This effort involves the search for and procurement of all the available and applicable written information on a source category. After these data and literature are reviewed, organized, and analyzed, the process descriptions, process flowsheets, and other background portions of the section are prepared. Using information compiled, representative emission factors are developed for each pollutant emitted at each emission point of the particular process. These factors are usually obtained by application of a combination of engineering judgment and statistical manipulation in an attempt to describe the representative or typical plant. When feasible, the ranges in the factors are presented for further clarity. The statistical manipulations involved may range in complexity from simple averaging of limited simple measurements to a rather vigorous regression and correlation analysis with various process variables that may exist. Occasionally, enough data exist to permit the development of either empirical or theoretical formulas (or graphs) relating emission factors to various process parameters such as stream temperature, sulfur content, or catalyst depletion. In these cases, representative values of these process parameters are selected and substituted into the formulas or graphs that, in turn, yield representative emission factors which are then tabulated. The pertinent formulas and graphical data are also normally included to provide the flexibility needed for estimation of "custom" emission factors when the process conditions differ from those present in AP-42.

The reader must be cautioned not to use emission factors indiscriminately. That is, the factors generally will not permit the calculation of accurate emissions measurements from an individual installation. Only an on-site source test can normally provide data sifficiently accurate and precise to use in such undertakings as the design and purchase of control equipment or the initiation of a legal action. Factors are more valid when applied to a large number of processes as, for example, when emission inventories are conducted as part of community or nationwide air pollution studies. Emission inventories and emission factors are thus probably best described as technical tools for use in management analysis activities such as control strategy development, program assessment, or other facets of air resource management.

Emission factors are normally the most sensitive components of emission inventories in terms of inventory error. Thus, it is important that published factors in AP-42 be comprehensive and up-to-date with the "state of knowledge" regarding various sources. Consequently, AP-42 is updated with periodical supplements which add, or otherwise revise factors to reflect recent information on newly identified and measured sources; to reflect subtle or gradual changes in process design and operation; to reflect a new review of accepted factors (generally for major sources) which have been in use for many years; and occasionally, to correct errors or unclear passages that may have been discovered.

Continuing efforts at EPA to collect data for emission factor enhancement are both active and passive. New emission factors may be acquired as a direct result of source testing funded and initiated solely or primarily for the purpose of development of emission factors (active), or as a "by-product" of data collection (testing) for purposes such as enforcement, research, etc. (passive). Due to the extremely high costs for source testing and the many testing efforts that are carried out independent of emission factor development, most data collection tends to be under the passive mode. Future attempts to obtain results from the many testing programs being carried out by EPA, State and local agencies, other government agencies, and private industry are also undertaken. Maintaining cognizance of these activities in itself is often a somewhat monumental task.

To assist EPA in collecting and keeping track of source test data that may be available and to maximize the utilization capabilities if such data, the SOurce Test DATa (SOTDAT) system has been developed. This system keyed to the National Emission Data System (NEDS - a nationwide emission inventory system, is maintained by data supplied by the States to EPA through the EPA Regional Offices) allows for storage and retrieval of various air pollution source tests which are conducted by a variety of sources. Data stored in this system provides a supplementary source of raw test data for use with literature and other data available in development of emission factors. With this background in mind, let me discuss how this applies to fugitive emissions and fugitive dust sources.

Status of Fugitive Process Emission Factors

Reflecting the concern of EPA with regard to "fugitives" and their impact upon air quality, the U. S. Environmental Protection Agency has initiated development of various measurement techniques and programs to provide quantitative assessment of various sources. As evidenced by this meeting, the Agency is continuing its effort towards improving the measurement techniques and quality and comprehensiveness of the data base. Many groups within EPA have undertaken various projects to attempt to quantify or develop methods to quantify fugitive dust and fugitive process emission sources even beyond what one might surmise from examining the agenda for this meeting. A complete list would be too long for inclusion in this paper and, in fact, it would be very difficult to assemble because of the number and diversity of such efforts.

As an indication of the status of our assessment efforts, let us examine as an example an effort which EPA is now completing (under contract) entitled "Control Program Guideline for Industrial Process Fugitive Particulate Emissions" (discussed in more detail on the program for this meeting). This essentially is a distillation and summary of the "state-of-the-art" for estimating fugitive particulate emissions for a wide range of sources. With the upcoming revision to State Implementation Plans (SIPS's) which have been requested by EPA in many areas not meeting the NAAQS for TSP, air pollution control agencies at all levels have expressed concern relative to the proper fashion in which approach, evaluate, and handle fugitive particulate emissions from industrial operations. Thus, this project was developed to pull together all available information on the subject.

The guideline addresses:

- Industrial process fugitive particulate emission sources
- Control technology for these defined sources
- Conceptual procedures to use to estimate their impact on ambient air quality
- Guidance to the States for integration of source impact for such sources into the SIP process

Although the results of this project are very timely and useful, one of the major findings of the study and review was that there is a general lack of adequate test data for development of comprehensive and defensible emission factors for fugitive process emission sources. Although the estimates and emission factors derived through this effort are scheduled to be included in a supplement to AP-42, many of these factors are recognized as in need of additional investigation. Weak factors and gap areas have been defined which need to be systematically approached, examined in more detail, and specific sampling accomplished to fill in gaps and strengthen areas of weakness in data.

Fugitive emissions, of course, are not limited to TSP though this pollutant has received major emphasis in this discussion. Other pollutants may surface as areas of concern as our knowledge broadens. The Air

Management Technology Branch (in cooperation with the National Air Data Branch which currently has publication responsibilities), Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, is now involved in incorporating available fugitive emission factors into AP-42 as they become available. Unfortunately, the mechanism for accomplishing this objective in each case is usually unique. In some instances, it may be possible to incorporate development of an AP-42 section with an accompanying background support document into a larger assessment contract effort. In other cases, it may be necessary to issue an independent contract to develop AP-42 sections from existing data or from source test data collected from specific field work. In other instances, we may develop a test procedure, gather data, analyze it, and write the appropriate AP-42 section in-house. In-house resources available for this activity, however, are limited and must be utilized very efficiently.

Table 2 contains a list of selected sources of fugitive emission and fugitive dust for which we currently need additional data for improvement. The list is by no means meant to be all inclusive or complete or to say that existing factors in use are not useful, but is shown to give you an idea of the direction in which we are headed and to give some indication of areas for which we expect to be seeking data and/or publishing revised factors in the next several months. Other related fugitive sources will be characterized concurrently with those shown if data become available.

At the present time, there are many efforts underway to characterize fugitive emissions which hopefully will be amenable to incorporate into AP-42 and fill some of the identified gaps. Both government and private

Table 2

Selected List of Fugitive Emission and Fugitive Dust Categories Most Critically in Need of Emission Factor Improvement

Fugitive Process

- Iron and Steel
- Primary Non-Ferrous
- Secondary Non-Ferrous
- Foundries
- Portland Cement
- Lime Manufacturing
- Petroleum Industry
  - Extraction
  - Field Processing
  - Drains
  - Cooling Towers
  - Valves and Seals

Material Mining, Handling, and Storage

- Coal
- Sand and Gravel
- Stone
- Grains
- Fertilizers
- Pesticides
- Metallic Ores
- Fly Ash
- Wood Chips

Fugitive Dust

- Open Land
- Roads
- Parking Lots

(NOTE: The need for particle size data is becoming more critical for accurately depicting deposition in diffusion models which are frequently used to determine impact of fugitive emissions.)

industry are involved in these efforts. Table 3 is a selected list of several efforts, results of which are expected to provide us with input to our goal of making the latest information available to various control officials who rely upon AP-42 as a primary data source. Input from other such studies and organizations in establishing data needs and filling these gaps is solicited.

As these data become available and are incorporated into AP-42, and guideline documents containing additional background information are prepared, the State and local air pollution agencies will be better informed and able to cope with their local situations.

People in government and industry recognize the need for more accurate, up-to-date information in the area of emission characterization. There will be a continuing need for cooperation on the parts of government and private industry to see that data representing realistic emission characterization are available for use by agencies as required to develop and carry out air pollution implementation plans. This cooperative spirit is evidenced by this meeting and forum it provides. The number of such meetings seems to be increasing. As a matter of interest, a workshop specifically on emission inventories and emission factors is to be presented at Research Triangle Park, N.C., September 13-15. The focus of this meeting will be on organic emission factors and will address fugitive emissions as well as "stack" emissions.

Summary

Although the trend in air quality levels is generally downward, studies have shown that the impact of fugitive dust and emissions on

Table 3

List of Selected Projects Expected to Provide Input for AP-42 Emission Factor Development

Subject of Project	Responsible Organization
Iron, Steel and Gray Iron Control Technology Assessment of Fugitive Emissions	EPA/Industrial Environmental Research Laboratory, Research Triangle Park, N.C.
Sources Assessment of Fifty Industries for Environmental Risk	EPA/Industrial Environmental Research Laboratory, Research Triangle Park, N.C.
Emission Factor Analysis of the Iron and Steel Industry	American Iron and Steel Institute EPA/Office of Air Quality Planning and Standards, Research Triangle Park, N.C.
Fugitive Hydrocarbon Emissions from Vegetation	EPA/Office of Air Quality Planning and Standards, Research Triangle Park, N.C.
Re-entrainment of Dust from Paved Roads	EPA/Office of Air Quality Planning and Standards, Research Triangle Park, N.C.
Fugitive Dust Emissions from Coal Strip Mining	EPA/Region VIII, Denver, Colorado
Fugitive Emissions from the Rock Crushing Industry	EPA/Division of Stationary Source Enforcement, Washington, D.C.
Hydrocarbon Source Testing in the Los Angeles Air Basis	California Air Resources Board, Sacramento, California
Hydrocarbon Emissions from Storage Tanks	Western Oil and Gas Association, Los Angeles, California
Hydrocarbon Emissions from Loading Operations	Western Oil and Gas Association, Los Angeles, California
Hydrocarbon Emissions from Storage Tanks	American Petroleum Institute, Washington, D.C.
Fugitive Emissions from On- and Off-Shore Production Facilities	American Petroleum Institute Washington, D.C.

local air quality may be significant. Analysis of results of such studies lead to conclusions that fugitive sources must be considered in developing action strategies to meet the National Ambient Air Quality Standards. The impact of such sources has not been adequately addressed in most areas prior to this time, and were generally omitted in base year State Implementation Plan (SIP) inventories in part due to lack of existing emission factors. An examination of the status and role of emission factors needed for preparation of revised SIP's indicates that there are many areas with major data needs particularly in the context of availability and applicability of generalized factors to be utilized in AP-42, Compilation of Air Pollutant Emission Factors. A program to gather and incorporate data from various agencies and other organizations is underway and will hopefully provide State agencies and others with the data base needed for program development. This can only be accomplished by the continued cooperative interface between various government and private organizations.

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3. National Air Quality and Emission Trends Report, 1975, EPA-450/1-76-002, November 1976, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711.

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Monday Afternoon - May 23, 1977

SESSION II: MEASUREMENT

Chairman: James A. Dorsey, *EPA*

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Chatten Cowherd, Jr., Ph.D., *Midwest Research Institute*

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* indicates speaker

MEASUREMENT OF FUGITIVE PARTICULATE

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MEASUREMENT OF FUGITIVE PARTICULATE

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ABSTRACT

This paper describes an alternative to the upwind/downwind sampling strategy for use in quantifying particulate emissions from open (unconfinable) sources. Exposure profiling consists of the direct measurement of the total passage of airborne particulate downwind of the source by means of simultaneous multipoint sampling over the effective cross-section of the fugitive emissions plume. Samples are collected isokinetically by directing sampling intakes into the wind and by matching intake velocity to the local mean wind speed.

Exposure profiling offers distinct advantages over the upwind/downwind method in quantifying fugitive particulate emissions from open sources as required for control strategy development. The method yields source-specific emissions data needed to evaluate the effectiveness of control measures. Moreover, based on field tests of several types of open dust sources, the accuracy of measurements obtained by exposure profiling is better than that achievable by the upwind/downwind method, even with site-specific calibration of the dispersion model used in the latter method.

INTRODUCTION

Failure to attain national ambient air quality standards for total suspended particulates (TSP) in both urban and rural areas has spurred a detailed reexamination of the national TSP problem. As a result of this assessment, it has become evident that fugitive emissions sources contribute substantially to TSP levels in many of the nonattainment areas. The regional impact of fugitive sources of particulate matter is the result of emissions of fine particles which have the potential for atmospheric transport over substantial distances from the source.

Analysis of the impact of fugitive emissions of particulate matter must take into account the ranges of particle size associated with the adverse effects of particulate air pollution. Adverse health effects are generally attributable to particles smaller than about 5 micrometers (μm) in aerodynamic (equivalent sphere) diameter. Coarse particles tend to settle out over short drift distances, creating localized nuisance problems. However, dustfall on roadways or other unprotected areas is a source of fine particle emissions through the action of traffic and wind erosion.

The quantification of particulate emissions from fugitive sources is necessary to the rational assessment of the environmental impact created by these sources and to the development of effective control technology. In addition to mass rates of emission, information is needed on particle size distribution and the presence of toxic constituents within specific size ranges.

In large part, proven methods for quantifying fugitive emissions have not been fully developed. Atypical quantification problems are presented by the diffuse and variable nature of fugitive sources. Standard source testing methods, as written, strictly apply only to well defined, constrained flow fields with velocities above about 2 m/sec. Such methods are applicable to fugitive emissions only if it is possible to capture the entire plume by means of an enclosure or hooding device.

The Research Corporation of New England (TRC)(1) has defined the following three basic sampling strategies for measurement of fugitive emissions from most potentially significant sources:

1. The quasi-stack method involves capturing the entire emissions stream with enclosures or hoods and applying conventional source testing techniques to the confined flow.

2. The roof-monitor method involves measurement of concentrations and air flows across well-defined building openings such as roof monitors, ceiling vents and windows.

3. The upwind-downwind method involves measurement of upwind and downwind air quality, utilizing ground-based samplers under known meteorological conditions, and calculation of source strength with atmospheric dispersion equations.

This paper focuses on an alternative to the upwind/downwind sampling strategy for use in quantification of particulate emissions from open sources such as traffic on unpaved roads and aggregate materials handling operations. Exposure profiling consists of the direct measurement of the total passage of airborne particulate immediately downwind of the source by means of simultaneous multipoint sampling over the effective cross-section of the fugitive emissions plume. This strategy utilizes a calculation scheme similar to the quasi-stack or roof-monitor method rather than requiring the application of a dispersion model.

OPEN SOURCE QUANTIFICATION BY UPWIND/DOWNWIND METHOD

The upwind/downwind method has frequently been used to measure fugitive particulate emissions from open (unconfinable) sources. Typically, particulate concentration samplers (most often high-volume filtration samplers) are positioned at a considerable distance from the source (for example, at the property line around an industrial operation) in order to measure the highest particulate levels to which the public might be exposed. The calculation of the emission rate by dispersion modeling is often treated as having secondary importance, especially because of the difficult problem of identifying the contributions of elements of the mix of open (and possibly confinable) sources.

While the above strategy is useful in characterizing the air quality impact of an open source mix, it has significant limitations with regard to control strategy development. The major limitations are as follows:

1. Overlapping of source plumes precludes the determination of source specific contributions on the basis of particulate concentration alone.

2. Air samplers with poorly defined intake flow structure (including the conventional high-volume sampler) exhibit diffuse cutoff size characteristics for particle capture, which tend to be affected by wind conditions.(2)

3. Uncalibrated atmospheric dispersion models introduce the possibility of substantial error (a factor of three(3)) in the calculated emission rate, even if the stringent requirement of unobstructed dispersion from a simplified source configuration is met.

The first two limitations are not a direct consequence of the upwind/downwind method but of the way it is used. These limitations could be removed by using samplers designed to capture all or a known size fraction of the atmospheric particulate, and by designing sampler placement to isolate the air quality impact of a well-defined source operation.

However, there would remain the need to improve method accuracy by calibration of the dispersion model for the specific conditions of wind, surface roughness, and so on, which influence the near-surface dispersion process. This need is evident from the significant size of the variation in model-calculated emission rates for aggregate process operations, based on data from individual samplers operated simultaneously at different downwind locations.(4) The suggested use of tracers for this purpose is complicated by the characteristically diffuse and variable nature of an open dust source and the need for a polydisperse tracer test approximating the particle size distribution of the source emissions.

EXPOSURE PROFILING METHOD

The exposure (total mass flux) profiling method was developed by Midwest Research Institute(5,6) to measure particulate emissions from specific open sources, utilizing the isokinetic profiling concept which is the basis for conventional source testing. For measurement on nonbuoyant fugitive emissions, sampling heads are distributed over a vertical network positioned just downwind (usually about 5 meters) from the source. Sampling intakes are pointed into the wind and sampling velocity is adjusted to match the local mean wind speed, as monitored by distributed anemometers. A vertical line grid of samplers is sufficient for measurement of emissions from line or moving point sources while a two-dimensional array of samplers is required for quantification of area source or point source emissions.

GRID SIZE AND SAMPLING DURATION

Sampling heads are distributed over a sufficiently large portion of the plume so that vertical and lateral plume boundaries may be located by spatial extrapolation of exposure measurements. The size limit of area sources for which exposure profiling is practical is determined by the feasibility of erecting sampling towers of sufficient height and number to characterize the plume. This problem is minimized by sampling when the wind direction is parallel to the direction of the minimum dimension of the area source.

The size of the sampling grid needed for exposure profiling of a particular source may be estimated by observation of the visible size of the plume or by calculation of plume dispersion. Grid size adjustments may be required based on the results of preliminary testing.

Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). For example, if the exposure from a point source is normally distributed, as shown in Figure 1, the exposure values measured by the samplers at the edge of the grid should be about 25% of the centerline exposure.

Sampling time should be long enough to provide sufficient particulate mass and to average over several units of cyclic fluctuation in the emission rate (for example, vehicle passes on an unpaved road). The first condition is easily met because of the proximity of the sampling grid to the source.

Assuming that sample collection media do not overload, the upper limit on sampling time is dictated by the need to sample under conditions of relatively constant wind direction and speed. In the absence of passage of weather fronts through the area, acceptable wind conditions might be anticipated to persist for a period of 1 to 6 hr.

CALCULATION PROCEDURE

The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, can be obtained by spatial integration (over the effective cross-section of the plume) of distributed measurements of exposure (mass/area). The exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement.

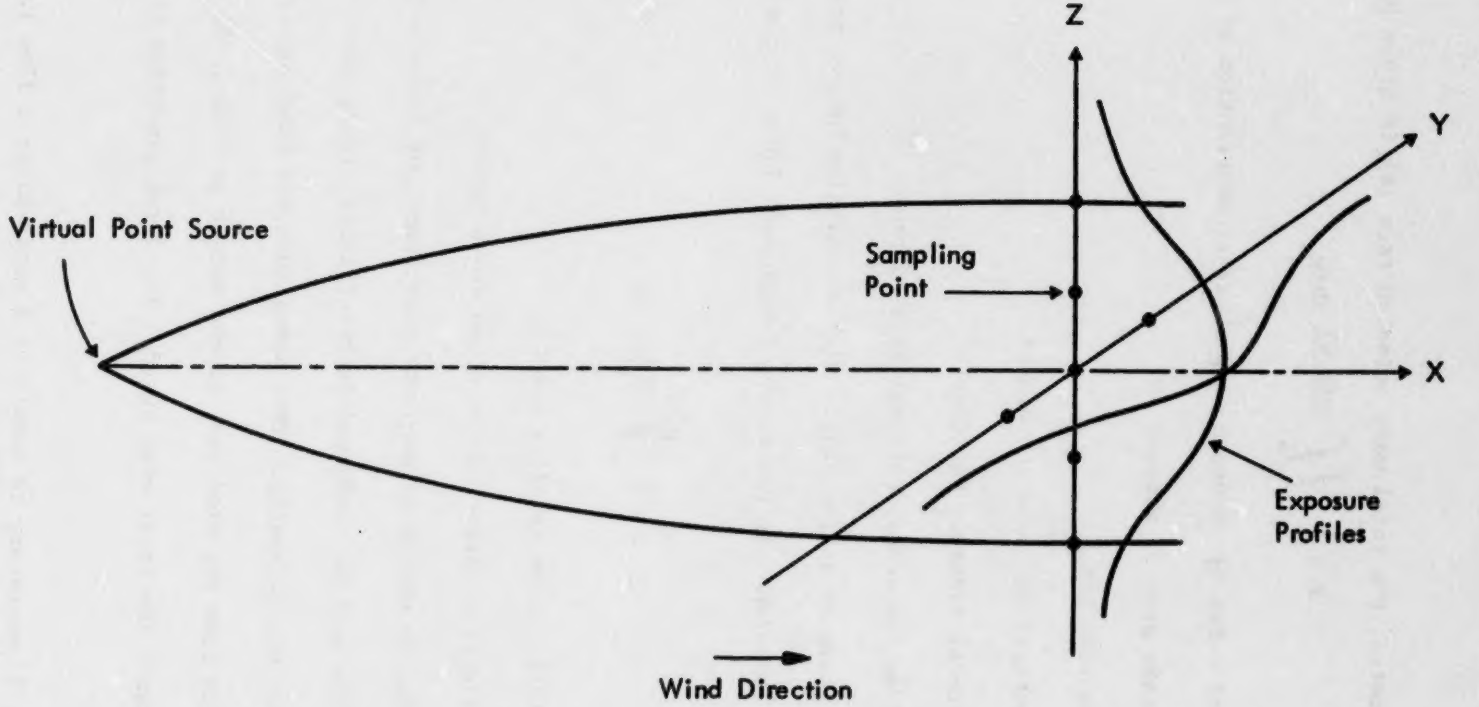
Virtual Point Source
Sampling Point
Z
Y
X
Exposure Profiles
Wind Direction

Figure 1. Example Exposure Profiling Arrangement

Mathematically stated, the total mass emission rate (R) is given by:

$$R = \frac{1}{t} \iint_A \frac{m(h,w)}{a} \, dh dw$$

where m = dust catch by exposure sampler after subtraction of background

a = intake area of sampler

t = sampling time

h = vertical distance coordinate

w = lateral distance coordinate

A = effective cross-sectional area of plume

In the case of a line source with an emission height near ground level, the mass emission rate per source length unit being sampled is given by:

$$R = \frac{W}{t} \int_0^H \frac{m(h)}{a} \, dh$$

where W = width of the sampling intake

H = effective extent of the plume above ground

In order to obtain an accurate measurement of airborne particulate exposure, sampling must be conducted isokinetically, i.e., flow streamlines enter the sampler rectilinearly. This means that the sampling intake must be aimed directly into the wind and, to the extent possible, the sampling velocity must equal the local wind speed. The first condition is by far the more critical.

If it is necessary to sample at a nonisokinetic flow rate (for example, to obtain sufficient sample under light wind conditions), multiplicative factors may be used to correct measured exposures to corresponding isokinetic values.(5,6) These corrections require information on the particle size distribution of the emissions.

High-volume cascade impactors with glass fiber impaction substrates, which are commonly used to measure particle size distribution of atmospheric particulate, may be adapted for sizing of fugitive particulate. A cyclone preseparator (or other device) is needed to remove coarse particles which otherwise would be subject to particle bounce within the impactor causing fine particle bias.(6) Once again, the sampling intake should be pointed into the wind and the sampling velocity matched to the mean local wind speed.

Midwest Research Institute has used the exposure profiling method to develop emission factors for unpaved (dirt and gravel) roads,(5,6) agricultural tilling,(5) aggregate storage piles (crushed stone,(5) iron ore and slag(7)), and dust entrainment from paved roadways.(6) Emission factors have been derived for particles smaller than 30 μm in diameter (the approximate aerodynamic cutoff diameter for capture of fugitive dust by a standard high-volume filtration sampler,(5) (based on a particle density of 2.0 - 2.5 g/cm^3) and for particles smaller than 5 μm.

Figure 2 shows the intake design used in profiling atmospheric dust entrained by traffic on paved urban roadways. Intake velocity is adjustable up to 15 mph. The sample stream passes through a settling chamber and then upward through a standard 8 in. by 10 in. glass fiber filter positioned horizontally. Figure 3 gives particulate concentration profiles measured 5 meters downwind of a 4-lane paved roadway with a traffic density of about 500 vehicles/hour.(6)

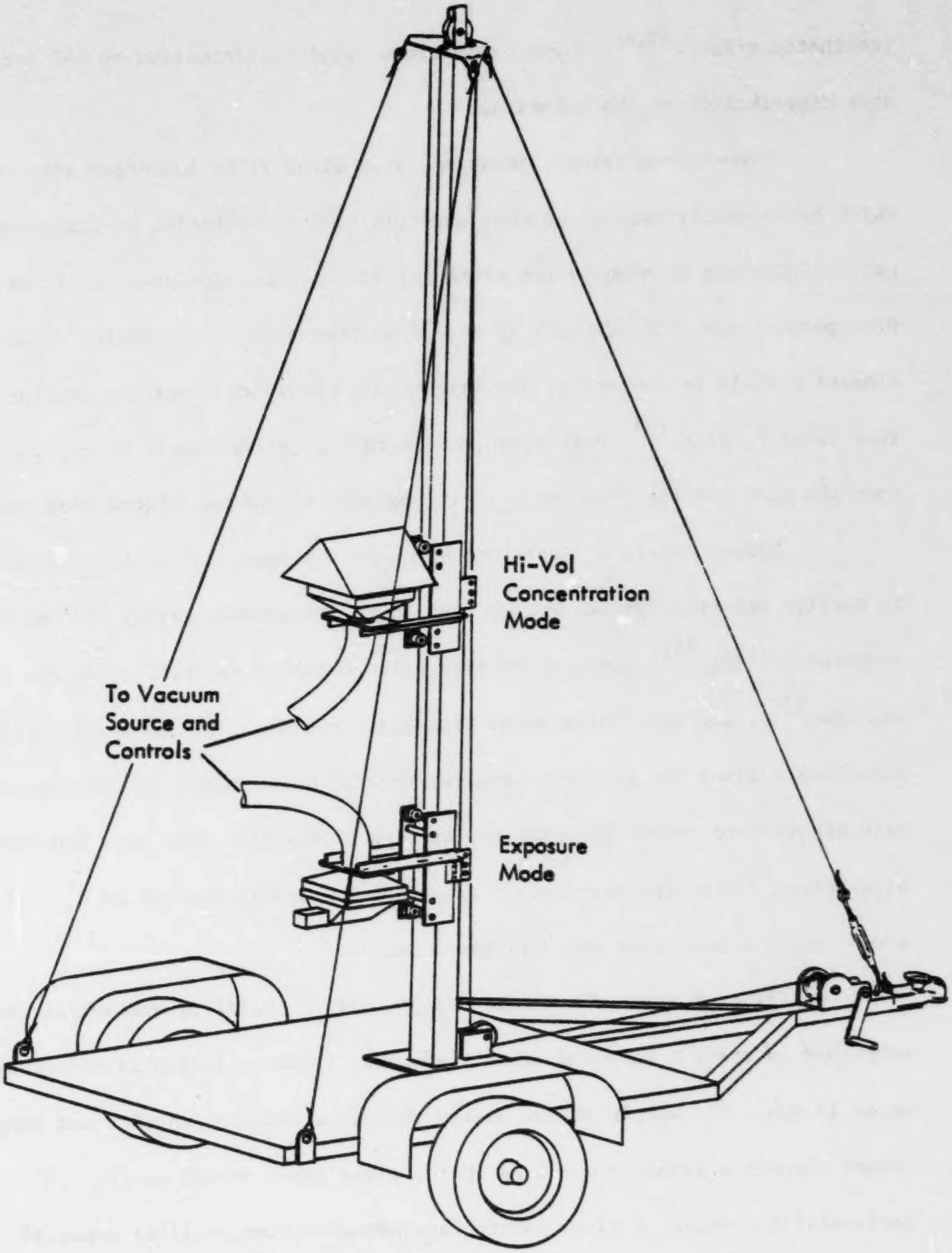
Hi-Vol
Concentration
Mode
To Vacuum
Source and
Controls
Exposure
Mode

Figure 2. MRI Exposure Profiler

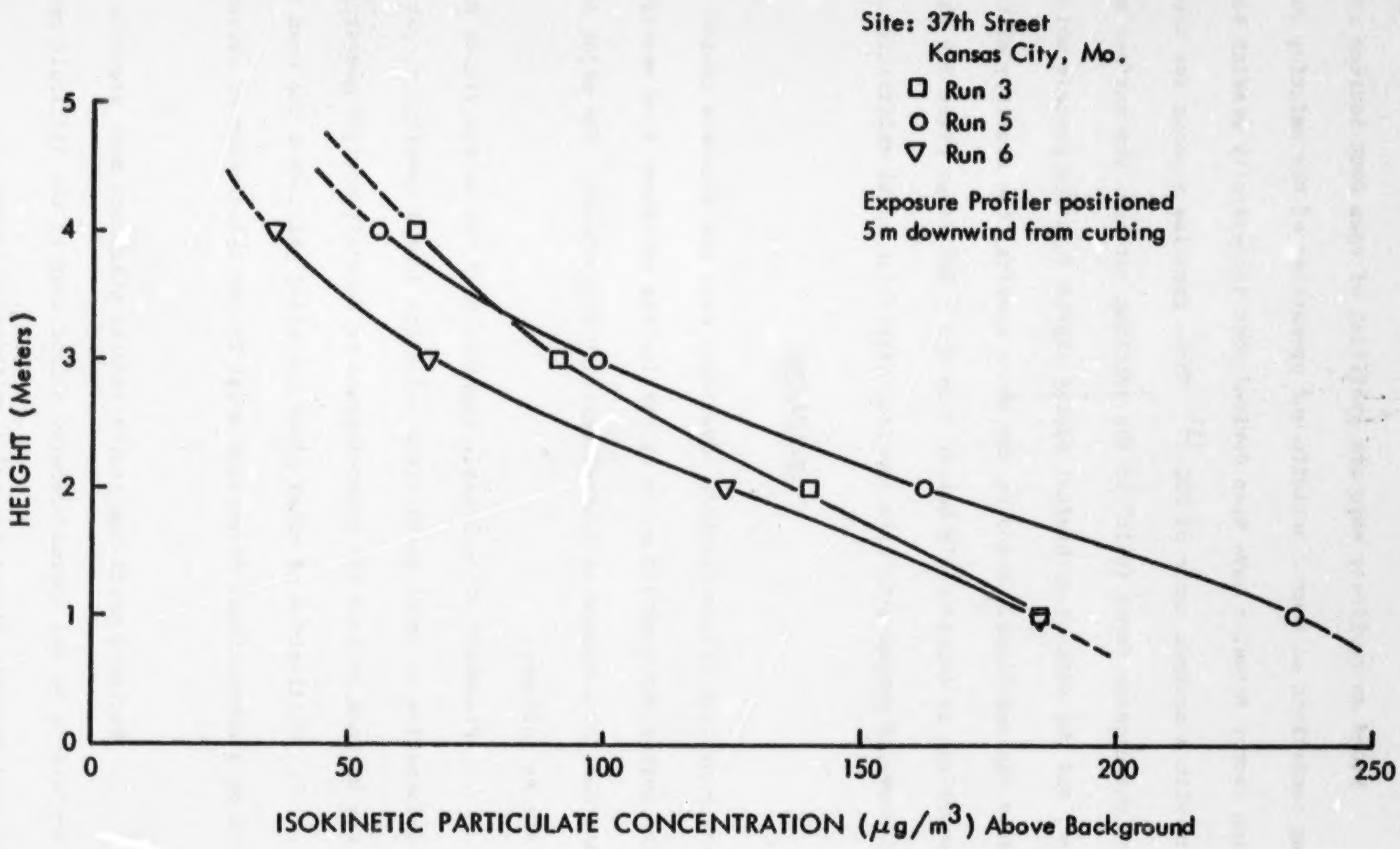

Figure 3. Vertical Profiles of Particulate Concentration (Street Dust Entrainment)

Based on replicate exposure profiling of open dust sources under varying conditions of source activity and properties of the emitting surface, emission factor formulae have been derived that successfully predict test results with a maximum error of 20%.(5) These formulae account for the fraction of suspendable fines (silt) in the emitting surface, the surface moisture content, and the rate of mechanical energy expended in the process which generates the emissions. Based on the above results, the accuracy of exposure profiling is considerably better than the ± 50% range given for the upwind/downwind method with site-specific dispersion model calibration.

CONCLUSIONS

Exposure profiling offers distinct advantages over the standard upwind/downwind method for quantification of particulate emissions from specific open sources for purposes of control strategy development. The major advantages are as follows:

1. Placement of isokinetic samplers near the source yields definitive information on total particulate emissions from a specific operation, which can be used to test the effectiveness of specific control measures.

2. Utilization of total plume profiling eliminates the need for reliance on a conventional dispersion model in the calculation of emission rate.

3. Exposure profiling yields results which are more accurate than those achievable by the upwind/downwind method even if the difficult requirement of site-specific dispersion model calibration is met.

These conclusions establish the value of exposure profiling in quantifying particulate emissions from open sources as required for effective source-specific control strategy development.

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FUGITIVE MONITORING AT A COAL CLEANING PLANT SITE

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ABSTRACT

This paper presents preliminary procedures and findings of a fugitive dust monitoring effort about a large coal cleaning plant. Hi-volume samplers were the primary instrument of measurement; limited data concerning particle sizing is presented. Extensive meteorological data is offered.

Microscopic and chemical analysis was performed. Data suggesting geographical migration of select metals are displayed.

Preliminary data is presented which compares chemical concentrations with mass weights obtained under a specific meteorological setting.

The coal cleaning plant was not in operation during the monitoring efforts. The main thrust was to define pre-operational loadings (fugitive) so as to permit a comparison with the near future loadings when this large coal cleaning plant becomes operational.

INTRODUCTION

This grab sampling effort was conducted as part of a program for environmental assessment of coal cleaning processes under a current contract from the Fuel Process Branch, Energy Assessment and Control Division, Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

This paper presents an outline of particulate measurement activities and the requisite computer modeling/simulation. Analytical results of the chemical nature of the captured particulates are given. The micro-meteorology that occurred during the field effort is provided and interpreted. The results of a microscopic examination of the particulates are included in this paper.

A detailed discussion of the theory and mechanics of wide area source modeling procedure is outlined herein.

The last segment of this paper concludes the efforts of this grab sampling experience. This summary provides information about the apparent fall-out rates as compared with geographical distances downwind from target sources. Trends in the relationships of chemical concentration inherent in particulates from coal source areas are given. Loading values of weekend periods vs work week periods are provided. Suggestions as to the diurnal loading variations are included.

BACKGROUND

Study Objectives

An intense environmental assessment of a coal cleaning facility has been undertaken by Battelle's Columbus Laboratories at the site of an Appalachian generating station.

One portion of the environmental assessment was devoted to evaluating air quality impacts deriving from sources of fugitive dust located in the area of plant operations prior to the start up of the coal cleaning facility at the Appalachian power station. Battelle's objectives in this portion of the assessment were twofold: one, to identify the types of pollutants emitted from the fugitive dust sources, and two, to determine through site monitoring the amount of material that is being deposited on downwind sites.

Objectives of Air Monitoring

Three air monitoring campaigns, each extending for 48 hours, commencing in December, 1976, and ending in April, 1977, were conducted by Battelle. At the outset of the study the purpose for on-site air monitoring was to determine ambient or background levels of total suspended coal and ash particulates before the start-up of the coal cleaning plant. However, due to time constraints imposed and to the limitations of data analysis imposed by non-continuous on-site monitoring, the objectives were later modified to collecting grab samples from which a more comprehensive sampling program could be developed for future studies during the coal cleaning plant's interim and final plant configuration.

All three air monitoring campaigns were conducted prior to the operation of the coal cleaning facility. The first monitoring period took place from 2000 December 17, 1976, to 2000 December 19, 1976. The second and third air monitoring campaigns were also of 48-hour duration and occurred from 2000 January 5 to 2000 January 7, 1977, and from 2000 April 5 to 2000 April 7, 1977, respectively.

Objectives of Diffusion Modeling

In studying potential areas for locating air monitors it was decided that a diffusion analysis be undertaken to indicate a range of distances where the maximum concentrations may be found from each of the fugitive dust sources. An area source mathematical diffusion model was developed not only to validate the final determination of the areas selected for monitoring but also to predict with reasonable accuracy concentrations of fugitive dust at any desired receptor location.

General Description of Site

An intense environmental assessment of a coal cleaning facility was undertaken by Battelle's Columbus Laboratories at the site of an Appalachian generating station. The Appalachian power station is intended to supply electrical energy to thousands of consumers throughout the region.

The power station consists of two generator units that utilize superheated steam from two boilers, each 40' x 66' x 151', to transform mechanical energy to electrical energy. The boilers are fired by tons of pulverized coal. Air pollutants are discharged through two tall stacks. The stacks were constructed to these heights to help assure an effective level of dispersion.

MEASUREMENTS

Criteria in Selecting Monitoring Sites

In designing an air monitoring system, the first consideration is generally given to the intent for monitoring. Are maximum concentrations of primary interest or is a spatial representation of average concentrations of special importance? Battelle, in monitoring fugitive dust about this coal cleaning facility, wished to obtain both a spatial distribution of the dust deposition and the magnitude of the maximum concentrations. The second important consideration in designing a monitoring system is the nature of emissions. Since the sources in the study area are fugitive in nature, it is reasonable to assume that the greatest impacts will occur within short distances downwind and therefore monitoring efforts should be concentrated in close proximity of the sources.

Ten monitoring sites were carefully selected in accordance with the criteria established above. Depicted in Figure 1 are the location of the monitoring sites. Five sites (Nos. 1, 2, 3, 4, and 7) are located in the immediate vicinity of the power plant operations. The remaining sites (Nos. 5, 6, 8, 9, and 10) are well removed from the center of plant operations. Ideally, a monitoring system is designed to produce a set of samples that represent a spatial distribution of pollutant concentration. The monitoring system established at the Appalachian power plant may be somewhat less than an ideal system in that power availability and climatological features of the area must be realistically factored into such field studies. For future studies the monitoring system may include additional

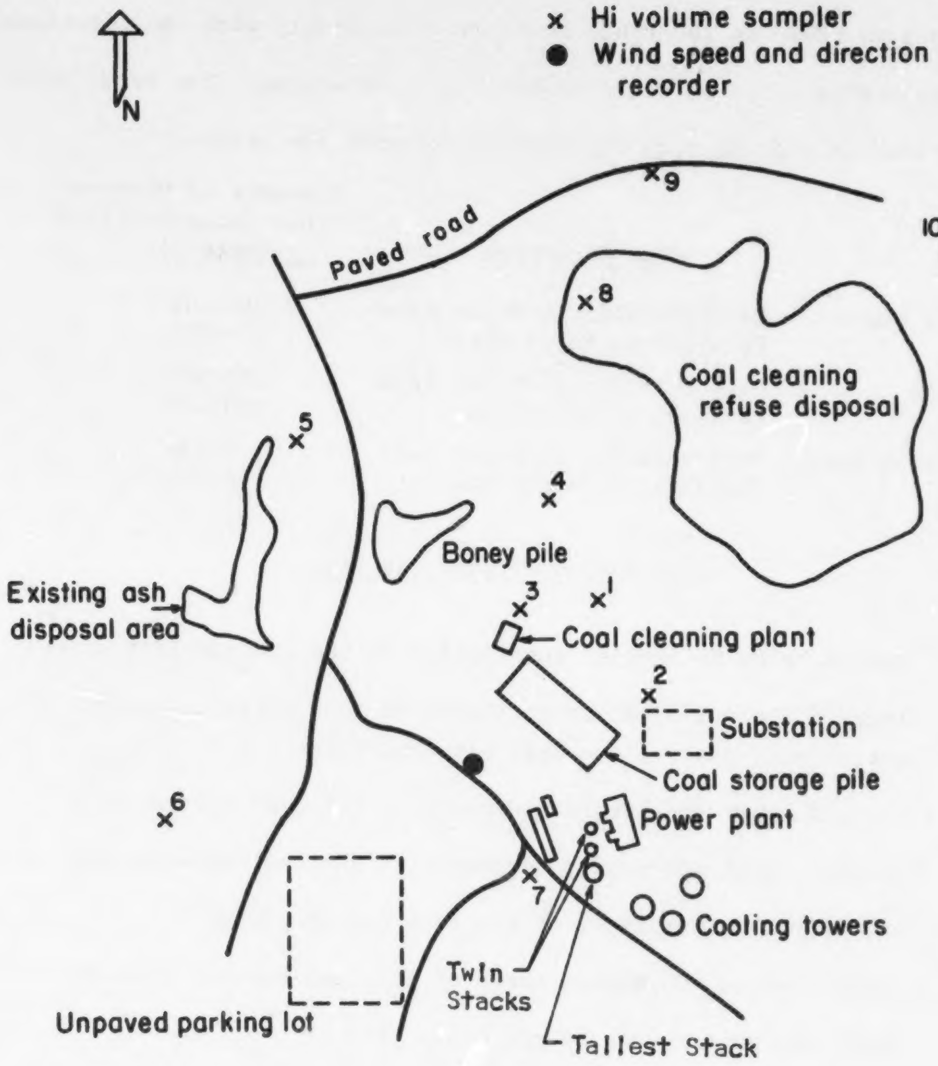
N
× Hi volume sampler
● Wind speed and direction recorder
Paved road
9
10
8
Coal cleaning refuse disposal
5
4
Boney pile
Existing ash disposal area
3
1
Coal cleaning plant
2
Substation
Coal storage pile
6
Power plant
7
Cooling towers
Twin Stacks
Tallest Stack
Unpaved parking lot

FIGURE 1. LOCATION OF SOURCES AND MONITORING SITES AT COAL CLEANING AND POWER PLANT (Not Drawn to Scale)

monitoring sites and additional particle sizing monitors.

Shown below are the results of Battelle's Fugitive Dust Emission Model which was utilized in studying potential sites for monitoring. The distances summarized in the table below agree favorably with the locations of the monitoring sites situated around plant operations. The term "major axis" is used in reference to the configuration of the source.

Source	Wind Direction	Distance of Maximum Fallout Concentrations (meters)
Coal Pile Plant	Perpendicular to Major Axis	250-400
	Parallel to Major Axis	400-500
Boney Pile	Perpendicular to Major Axis	150-300
	Parallel to Major Axis	200-400
Ash Disposal Area	Perpendicular to Major Axis	0-100
	Parallel to Major Axis	0-100

Description of Sampling Site

Listed below is a brief description of the ten sampling sites:

Site #1 - Located about 175 meters northeast of coal storage pile and 300 meters northeast of the coal cleaning plant.

Site #2 - Located about 200 meters southeast of the coal storage pile.

Site #3 - Located about 150 meters northwest of the coal storage pile and 50 meters northeast of the coal cleaning plant.

Site #4 - Located about 400 meters north of the coal storage pile and about 300 meters east of the boney pile.

Site #5 - Located about 200 meters east of the ash disposal area.

Site #6 - Located on a farm about 1600 meters southwest of the coal cleaning plant.

Site #7 - Located about 500 meters southwest of coal storage pile and adjacent to an employee parking lot at the company's property line.

Site #8 - Located about 1200 meters north of coal storage pile in an area that is being readied to handle the refuse from the coal cleaning plant.

Site #9 - Located about 1800 meters north of the coal storage pile near the company property line.

Site #10 - Located on a farm about 2200 meters northeast of the coal storage pile.

Figure 1 is a drawing of the plant site and location of the hi-volume samplers.

Description of the Sources

All of the fugitive dust sources, as inferred by the term fugitive, are partially or fully exposed to dispersion by the wind. Those sources on the power plant property include an ash disposal area, where flyash and bottom ash are routinely deposited by trucks; a boney pile, which serves as a refuse area for undesired coal from the mining operations; and a large coal pile from which coal is fed into the coal-fired boilers. Fugitive dust monitoring also occurred at a proposed refuse area for the coal cleaning plant. In addition, a modern coal cleaning facility adjacent to the power plant was also considered as a source of fugitive dust. These sources are depicted in

Figure 1. Notice the amount of land area some of these sources occupy.

The ash disposal area occupies an area of about 17.7 acres and is of irregular configuration. Here bottom and flyash are spread uniformly over the area; the height of the ash disposal area is only slightly above ground level.

The boney pile is also of irregular shape and covers an area of about 11.1 acres. It, however, extends well above the ground with an average height of 60 feet.

The largest source in both land area and expected airborne coal particles is the coal storage pile. It occupies an area of approximately 20 acres and is of rectangular configuration. The coal pile towers well above the ground averaging about 100 feet throughout its length.

The coal cleaning plant is a ten-story structure which will soon become completely enclosed. In the future, after the structure has been enclosed with sheet metal, it is expected that the rate of emissions that are common to older coal cleaning plants will be reduced.

Other fugitive sources near the coal cleaning plant operations include the dust generated by both vehicular traffic and construction activities. Construction has been ongoing for a number of years and is projected to remain so for at least two more years. There are also two coal storage silos which deposit coal carried by conveyor belts onto the coal pile. A significant amount of coal particles are released during this operation. The conveyor belts were not identified as a principal source of fugitive dust since they are almost fully enclosed. However, coal dust does emit from the bottoms of these conveyor belts.

Description of Fugitive Dust Sampling Campaigns

The fugitive dust sampling study consisted of three campaigns; namely Campaign I, December 17 to 19, 1976; Campaign II, January 5 to 7, 1977; and Campaign III, April 5 to 7, 1977. All three campaigns had the same sampling schedule which consisted of 6 samplers that were operated for a twelve-hour period beginning at 2000 hours and ending at 0800 hours, and 4 samplers that were operated for a 24-hour period beginning at 2000 hours and ending at 2000 hours. In addition to the 10 hi-volume samplers, a weather station was operated on site which recorded wind speed and wind direction during each campaign, and an Andersen sampler was operated during Campaign III. Three sites were supplied with electrical power by portable gasoline-fueled generators.

Sites were maintained by Battelle-Columbus and personnel provided by the power company. Operators maintained records of equipment malfunctions, such as generator failure, power failure, and charts failing to ink properly.

All samples were returned to Battelle-Columbus for analysis. Lab work included the weighing of hi-volume filter and microscopic analysis of the filter pads, and reduction of the meteorological data. After weighing and microscopic examination of each filter, selected hi-vol filters were forwarded to an independent lab for chemical analysis. Standard analytical procedures were used for all analysis.

Sampler Results

Presented below is a discussion and tabulation of analytical loading values and/or physical and chemical properties of the captured particulates.

Mass Concentrations

The general objective of this effort is to obtain quantitative and qualitative data on particulate matter generated by various fugitive dust sources.

Another objective was to determine if the fugitive dust was leaving the property of the coal cleaning plant (under construction) and impacting on the surrounding environment. Preliminary data indicate that fugitive dust has little impact on the surrounding environment.

All of the samples were collected on 8" x 10" fiberglass, hi volume filters, for either a 12-hour or 24-hour-period. Filters with minimum amounts of trace metals were used in Campaign III. The filters were weighed before and after each sampling to determine the mass of the particles collected. The weighing of samples was performed by Battelle-Columbus personnel.

Generally, the maximum concentrations were observed at Sites 1, 2, and 3. These sites are located adjacent to the coal storage pile; also the maximum concentrations occurred during the 0800-2000 hours sampling periods. During the first campaign (Friday, December 17 - Sunday, December 19, 1976) sampling was conducted on the weekend to reduce the impact of fugitive emissions from construction activities. Table 1 presents the results of mass concentrations found at each sampling site for each time frame. The average (arithmetic) concentrations for the 12-hour samples was 114.0 $\mu g/m^3$, while the average for 24-hour samples was 52 $\mu g/m^3$. The maximum and minimum concentrations for the 12-hour samples were 564.0 and 30.0 $\mu g/m^3$, respectively, while the maximum and minimum concentrations for the 24-hour samples were 11.0 $\mu g/m^3$ and 28.0 $\mu g/m^3$, respectively.

TABLE 1. EXPERIMENTAL PARTICULATE CONCENTRATIONS NEAR COAL CLEANING PLANT OBTAINED BY HI VOLUME SAMPLER

Sampler Location	Date	Time	Suspended Particulate Concentration (μg/m^3)
		12-Hour Samples	
1	17-18 Dec 76	2000-0800	78.0
	18 Dec 76	0800-2000	Invalid data
	18-19 Dec 76	2000-0800	Invalid data
	19 Dec 76	0800-2000	Invalid data
	5-6 Jan 77	2000-0800	54.0
	6 Jan 77	0800-2000	136.0
	6-7 Jan 77	2000-0800	60.0
	7 Jan 77	0800-2000	56.0
	5-6 Apr 77	2000-0800	149.0
	6 Apr 77	0800-2000	124.0
	6-7 Apr 77	2000-0800	252.0
	7 Apr 77	0800-2000	398.0
2	17-18 Dec 76	2000-0800	107.0
	18 Dec 76	0800-2000	69.0
	18-19 Dec 76	2000-0800	60.0
	19 Dec 76	0800-2000	306.0
	5-6 Jan 77	2000-0800	59.0
	6 Jan 77	0800-2000	230.0
	6-7 Jan 77	2000-0800	63.0
	7 Jan 77	0800-2000	294.0
	5-6 Apr 77	2000-0800	79.0
	6 Apr 77	0800-2000	168.0
	6-7 Apr 77	2000-0800	209.0
	7 Apr 77	0800-2000	291.0
3	17-18 Dec 76	2000-0800	75.0
	18 Dec 76	0800-2000	87.0
	18-19 Dec 76	2000-0800	72.0
	19 Dec 76	0800-2000	70.0
	5-6 Jan 77	2000-0800	82.0
	6 Jan 77	0800-2000	189.0
	6-7 Jan 77	2000-0800	58.0
	7 Jan 77	0800-2000	92.0

TABLE 1. (Continued)

Sampler Location	Date	Time	Suspended Particulate Concentration ($\mu g/m^3$)
	5-6 Apr 77	2000-0800	164.0
	6 Apr 77	0800-2000	149.0
	6-7 Apr 77	2000-0800	220.0
	7 Apr 77	0800-2000	564.0
4	17-18 Dec 76	2000-0800	30.0
	18 Dec 76	0800-2000	48.0
	18-19 Dec 76	2000-0800	75.0
	19 Dec 76	0800-2000	100.0
	5-6 Jan 77	2000-0800	75.0
	6 Jan 77	0800-2000	59.0
	6-7 Jan 77	2000-0800	52.0
	7 Jan 77	0800-2000	50.0
	5-6 Apr 77	2000-0800	106.0
	6 Apr 77	0800-2000	46.0
	6-7 Apr 77	2000-0800	143.0
	7 Apr 77	0800-2000	145.0
5	17-18 Dec 76	2000-0800	31.0
	18 Dec 76	0800-2000	47.0
	18-19 Dec 76	2000-0800	71.0
	19 Dec 76	0800-2000	45.0
	5-6 Jan 77	2000-0800	106.0
	6 Jan 77	0800-2000	86.0
	6-7 Jan 77	2000-0800	43.0
	7 Jan 77	0800-2000	46.0
	5-6 Apr 77	2000-0800	46.0
	6 Apr 77	0800-2000	49.0
	6-7 Apr 77	2000-0800	87.0
	7 Apr 77	0800-2000	69.0
8	17-18 Dec 76	2000-0800	39.0
	18 Dec 76	0800-2000	58.0
	18-19 Dec 76	2000-0800	63.0
	19 Dec 76	0800-2000	59.0
	5-6 Jan 77	2000-0800	76.0
	6 Jan 77	0800-2000	115.0
	6-7 Jan 77	2000-0800	62.0
	7 Jan 77	0800-2000	45.0

TABLE 1. (Continued)

Sampler Location	Date	Time	Suspended Particulate Concentration ($\mu g/m^3$)
	5-6 Apr 77	2000-0800	85.0
	6 Apr 77	0800-2000	105.0
	6-7 Apr 77	2000-0800	98.0
	7 Apr 77	0800-2000	191.0
24-Hour Samples			
6	17-18 Dec 76	2000-2000	33.0
	18-19 Dec 76	2000-2000	47.0
	5-6 Jan 77	2000-2000	76.0
	6-7 Jan 77	2000-2000	39.0
	5-6 Apr 77	2000-2000	28.0
	6-7 Apr 77	2000-2000	38.0
7	17-18 Dec 76	2000-2000	64.0
	18-19 Dec 76	2000-2000	88.0
	5-6 Jan 77	2000-2000	110.0
	6-7 Jan 77	2000-2000	48.0
	5-6 Apr 77	2000-2000	54.0
	6-7 Apr 77	2000-2000	67.0
9	17-18 Dec 77	2000-2000	33.0
	18-19 Dec 77	2000-2000	Invalid data
	5-6 Jan 77	2000-2000	45.0
	6-7 Jan 77	2000-2000	41.0
	5-6 Apr 77	2000-2000	39.0
	6-7 Apr 77	2000-2000	42.0
10	17-18 Dec 76	2000-2000	33.0
	18-19 Dec 76	2000-2000	57.0
	5-6 Jan 77	2000-2000	82.0
	6-7 Jan 77	2000-2000	41.0
	5-6 Apr 77	2000-2000	37.0
	6-7 Apr 77	2000-2000	57.0

There was one valid measurement conducted with the particle sizing sampler. These data are presented in Table 2.

Microscopic Analysis

The objective of the microscopic analysis was to provide a distinction between the various fugitive dusts such as pollen, construction dust, coal dust, and coal ash dust.

Each pad was examined under a low-power stereo microscope to see if the particulate matter was evenly distributed and if the pads were smeared during handling. Once these conditions were ascertained, a small piece, approximately 1/2 inch square, was cut from the pad and further analyses were conducted on these small pieces. The small pieces of filter pad were placed on a glass slide and a drop of lens immersion oil (index refraction = 1.5150) and a cover slip placed over the filter. The immersion oil matted the glass fibers in the pad and made them transparent.

Optical examinations were made using two instruments: (1) a Leitz microscope using transmitted light, and (2) a Zeiss metallograph using reflected light either with dark field or polarized light illumination. All optical examinations were conducted at magnifications of approximately 500 diameters.

The estimates of coal and ash were in 10% intervals, i.e., 0-10, 10-20, 20-30, etc. No attempt was made to estimate the percentage of the tertiary category, although morphological and dark field/polarized light observations were made.

TABLE 2. DATA PRESENTATION OF PARTICLE SIZING SAMPLER[(a)]

Stage	Percent Loading In Size Range	Size Range (microns)
1	33.3	7.0 and above
2	13.2	3.3 - 7.0
3	5.9	2.0 - 3.3
4	3.4	1.1 - 2.0
Backup Filter	44.2	0 - 1.1

(a) Sampler was located at Site #3.

Chemical Analysis

The chemical analysis of hi-volume filters was designed for coal or coal ash which we assumed to be a significant portion of the particulate, particularly the 12-hour samples. Data from the microscopic analysis were used to determine which filters would be analyzed for trace elements. Generally, the filter that exhibited the highest percentage of coal or ash from each site was selected for chemical analysis. The following parameters were analyzed on each candidate hi volume filter.

Antimony
Arsenic
Beryllium
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Mercury
Nickel
Titanium
Vanadium
Zinc
Total Organic Carbon
Fluoride
Chloride

Beryllium, vanadium, and antimony were not observed at any of the sites and titanium was observed at two locations (Sites 1 and 2).

In order to provide a general indication of the trace metal levels encountered, brief summaries have been prepared. The reader is advised that these presentations are insufficient to establish a sufficient data base. Table 3 lists the average values of 12-hour samples and 24-hour samples as well as minimum and maximum levels for each time frame. Table 4 lists the average values of Campaign I and II for selected sites. Results of the analysis of Campaign III is not available at this time. These sites

TABLE 3. COMPARISON OF TRACE ELEMENT CONCENTRATION BETWEEN 12-HOUR SAMPLES AND 24-HOUR SAMPLES(a)

	Concentrations, μg/m^3												
	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Ti	Zn	Cl	F
					12-Hour Samples								
Average Arithmetic	.015	.015	.031	.194	2.73	.550	.036	.00017	.015	.86[a]	.25	1.59	2.71
Maximum	.053	.039	.064	.484	8.09	1.50	.093	.00041	.050	1.18	.43	3.40	7.48
Minimum	.005	.001	.016	.011	1.04	.230	.031	.00003	.006	.58	.08	.82	.39
					24-Hour Samples								
Average Arithmetic	.013	.009	.024	.119	1.84	.377	.029	.00005	.010	-	.13	.70	1.22
Maximum	.021	.020	.022	.230	2.34	.488	.063	.00008	.018	-	.17	1.30	2.40
Minimum	.007	.003	.013	.112	1.40	.268	.026	.00002	.001	-	.06	.33	.06

(a) The average of two observed values.

TABLE 4. COMPARISON OF TRACE ELEMENT CONCENTRATION OF SELECTED SITES[a]

Sampler Location	Concentration, ug/m^3													
	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Ti	V	Zn	Cl	F
1[b]	.021	.006	.064	.243	2.56	.598	.071	.00041	.007	1.18	-	.41	.95	7.48
3	.016	.014	.032	.402	2.81	.893	.078	.00019	.019	-	-	.37	2.31	3.47
4	.008	.008	.016	.048	1.47	.283	.029	.00009	.018	-	-	.14	.98	1.89
8	.014	.023	.018	.045	1.62	.405	.033	.00013	.004	-	-	.21	2.35	2.35
10	.017	.012	.017	.200	1.97	.437	.034	.00007	.006	-	-	.15	.29	.67
6	.013	.007	.015	.179	1.66	.310	.042	.00004	.010	-	-	.12	.26	.88

(a) These values listed are the averages of Campaigns I and II.

(b) These values are for Campaign II only.

are generally in a line from the coal pile at distances from 175 meters to approximately 2200 meters. Site No. 6 is off property and generally not affected by the emissions from the coal pile or power plant stacks and therefore serves as a background or a control site.

Trace element values vary widely among mass concentration ranges; i.e., a filter that weighed between 251 and 300 $\mu g/m^3$ had a reported value of .007 $\mu g/m^3$ of As and .001 $\mu g/m^3$ of Cd, whereas a filter that weighed between 0 and 50 $\mu g/m^3$ had reported values of .007 $\mu g/m^3$ of As and .030 $\mu g/m^3$ of Cd. These data indicate that filters exhibiting the highest mass concentrations may not exhibit the highest trace element concentrations. Table 5 illustrates how reported values for trace elements vary with mass concentrations and sampling time (12-hour/24-hour).

Weather Conditions Observed During Each Campaign

What follows is a chronological review of the weather conditions associated with each of the three experimental air monitoring campaigns. In addition, hourly averages of wind directions and wind speeds are tabulated in Tables 6-8 for each campaign. The wind speeds and wind direction shown in Tables 6-8 were determined by averaging data on weather strip charts taken near the site of the large coal storage pile. It became increasingly difficult to average a wind direction which fluctuated between all points of the compass. This type of fluctuation occurred primarily with calm wind conditions during two sampling nights, one in each of the first two monitoring campaigns. Fortunately, the fugitive dust loading was minimal during this environmental set.

TABLE 5. TRACE ELEMENT CONCENTRATIONS AS THEY RELATE TO MASS CONCENTRATION RANGES

12-Hour Samples ug/m 3	Concentrations, $\mu g/m^3$												
	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Ti	Zn	Cl	F
0-50	.007	.030	.022	.089	2.20	.320	.046	.00014	–	–	.29	2.0	2.0
	.005	.003	.019	.011	1.24	.285	.046	.0003	.050	–	.26	2.80	2.50
51-100	.017	.002	.023	.163	2.79	.500	.052	.00015	.006	–	.10	3.27	.39
	.015	.039	.020	.050	2.20	.810	.034	.00012	–	–	.20	1.10	2.20
	.012	.007	.016	.040	1.04	.351	.031	.00013	.007	–	.22	.36	2.49
	.015	.021	.021	.230	2.40	.730	.046	.00014	–	–	.29	.20	.20
	.011	.012	.013	.084	1.70	.280	.029	.00017	.027	–	.20	.82	1.50
	.008	.023	.020	.320	2.50	1.50	.055	.00025	.028	–	.31	3.40	3.30
101-150	.006	–	.060	.130	1.80	.2[illegible]0	.060	.00016	.020	–	.25	1.50	2.5
	.021	.006	.064	.243	2.56	.598	.071	.00041	.007	1.18	.41	.95	7.48
151-200	.024	.005	.043	.484	3.13	.585	.101	.00013	.014	–	.43	1.21	3.63
201-250	.053	.005	.045	.437	8.09	.614	.093	.00023	.021	.58	.41	.93	1.58
251-300	.007	.001	.041	.246	3.88	.369	.058	.00012	.010	–	.11	1.23	3.41
24-Hour Samples													
0-50	.011	.010	.014	.180	1.40	.320	.028	.00002	.013	–	.09	1.92	1.69
	.006	.013	.022	.200	1.90	.420	.060	.00007	.018	–	.17	.90	1.4
	.008	–	.016	.112	1.41	.268	.026	.00003	.003	–	.06	.58	1.75
51-100	.015	.003	.016	.178	1.92	.310	.056	.00005	.007	–	.09	1.92	1.69
	.007	.012	.020	.230	1.80	.340	.055	.00002	.001	–	.14	1.30	2.4
	.013	.020	.013	.230	1.90	.500	.026	.00008	.010	–	.17	.58	.94
	.022	.003	.020	.163	2.04	.373	.041	.00006	.002	–	.13	–	.40
101-150	.021	.003	.022	.137	2.34	.488	.063	.00006	.011	–	.15	.42	1.12

TABLE 6. WIND DIRECTION-WIND SPEED DATA, CAMPAIGN I
(2000 December 17 - 2000 December 19, 1976)

Time	Wind Direction, degrees	Wind Speed, m.p.h.	Time	Wind Direction, degrees		Wind Speed, m.p.h.
*2000-2100 Dec. 17	285	10	*2000-2100 Dec. 18	10 (315-90)	Variable	1
2100-2200	290	9	2100-2200	310 (225-350)	"	1.5
2200-2300	285	8	2200-2300	70 (0-135)	"	1.5
2300-0000	290	8.5	2300-0000	60 (10-135)	"	1
0000-0100 Dec. 18	290	8	0000-0100 Dec. 19	45	"	1
0100-0200	285	5	0100-0200	70 (45-110)	"	1
0200-0300	285	4	0200-0300	70	"	1.5
0300-0400	290	4.5	0300-0400	200	"	1
0400-0500	315	5.5	0400-0500	330	"	1.5
0500-0600	290 (270-330)	3.5	0500-0600	250	"	1.5
0600-0700	260 (210-300)	3	0600-0700	250	"	1.5
0700-0800	295 (270-360)	3	0700-0800	250	"	2
*0800-0900 Dec. 18	295 (270-330)	4	*0800-0900 Dec. 19	220		3.5
0900-1000	295 (270-330)	7	0900-1000	225		4
1000-1100	305 (270-360)	7	1000-1100	210		5
1100-1200	295 (250-315)	7.5	1100-1200	245		10
1200-1300	295 (250-350)	7	1200-1300	240		10
1300-1400	290 (250-360)	7	1300-1400	255		13
1400-1500	280	8	1400-1500	250		10.5
1500-1600	285	6,5	1500-1600	235		12
1600-1700	290	3	1600-1700	235		9.5
1700-1800	330	2	1700-1800	235		7.5
1800-1900	80	2.5	1800-1900	240		8
1900-2000	60	2.0	1900-2000	235		8

* Indicates initiation of Hi-Vol sampling period.

TABLE 7. WIND DIRECTION-WIND SPEED DATA, CAMPAIGN II
(2000 January 5 - 2000 January 7, 1977)

Time	Wind Direction, degrees	Wind Speed, m.p.h.	Time	Wind Direction, degrees	Wind Speed, m.p.h.
*2000-2100 Jan. 5	50	2.0	*2000-2100 Jan. 6	215	6.5
2100-2200	315	3.0	2100-2200	215	4.5
2200-2300	165	4.0	2200-2300	230	3.0
2300-2400	150	2.0	2300-2400	225	3.5
2400-0100	80	1.5	2400-0100	235	2.0
0100-0200	135	1.0	0100-0200	235	2.0
0200-0300	140	3.0	0200-0300	255	2.5
0300-0400	85	2.0	0300-0400	275	3.5
0400-0500	60	2.5	0400-0500	290	5.5
0500-0600	50	3.5	0500-0600	270	7.0
0600-0700	35	2.0	0600-0700	295	5.5
0700-0800	225	2.5	0700-0800	325	8.0
*0800-0900 June 6	230	2.0	0800-0900 June 7	305	8.5
0900-1000	242	2.0	0900-1000	310	11.5
1000-1100	235	2.5	1000-1100	290	12.5
1100-1200	230	4.0	1100-1200	295	13.0
1200-1300	240	4.0	1200-1300	315	14.0
1300-1400	230	5.0	1300-1400	310	14.5
1400-1500	237	7.0	1400-1500	315	14.5
1500-1600	225	10.0	1500-1600	290	14.0
1600-1700	225	8.5	1600-1700	290	12.0
1700-1800	225	7.5	1700-1800	280	9.0
1800-1900	225	8.5	1800-1900	265	7.5
1900-2000	220	7.5	1900-2000	260	5.0

* Indicates initiation of Hi-Vol sampling period.

TABLE 8. WIND DIRECTION-WIND SPEED DATA, CAMPAIGN III
(2000 April 5 - 2000 April 7, 1977)

Time	Wind Direction, degrees	Wind Speed, m.p.h.	Time	Wind Direction, degrees	Wind Speed, m.p.h.
2000-2100 April 5	260	16.0	2000-2100 April 6	300	6.5
2100-2200	265	17.0	2100-2200	280	8.0
2200-2300	270	18.0	2200-2300	275	4.5
2300-0000	285	9.0	2300-0000	270	8.0
0000-0100 April 6	275	11.5	0000-0100 April 7	260	6.5
0100-0200	265	9.5	0100-0200	260	6.0
0200-0300	265	18.5	0200-0300	260	7.0
0300-0400	270	15.0	0300-0400	260	6.0
0400-0500	265	14.0	0400-0500	225	3.5
0500-0600	270	18.5	0500-0600	210	4.0
0600-0700	270	19.0	0600-0700	225	3.5
0700-0800	270	17.5	0700-0800	225	8.0
*0800-0900 April 6	265	22.5	*0800-0900 April 7	230	12.0
0900-1000	275	17.0	0900-1000	235	14.5
1000-1100	275	16.0	1000-1100	220	16.5
1100-1200	295	13.5	1100-1200	240	15.5
1200-1300	270	19.0	1200-1300	250	13.5
1300-1400	275	14.0	1300-1400	230	14.0
1400-1500	288	17.0	1400-1500	230	16.0
1500-1600	298	12.5	1500-1600	235	16.0
1600-1700	330	15.0	1600-1700	230	9.0
1700-1800	310	15.0	1700-1800	225	9.5
1800-1900	305	12.0	1800-1900	215	4.0
1900-2000	310	11.5	1900-2000	140	3.5

* Indicates initiation of Hi-Vol sampling period.

Campaign I
2000 December 17, 1976 -
2000 December 19, 1976

December 17, 1976 - Friday. Light snow fell throughout the day accumulating between 1-2 inches by nightfall. Cloudy skies prevailed throughout most of the night; temperatures were well below freezing throughout the day and night.

December 18, 1976 - Saturday. By dawn, skies had cleared and some warming occurred throughout the day. The snow that fell the previous day melted by noon and by mid-afternoon much of the surface moisture had evaporated. Skies remained clear throughout the day and temperatures rose to about 32°F. Temperatures fell to the mid twenties during the night. Wind speeds were especially low due to the influences of a high pressure area situated 100 miles south of the power plant and also to a nighttime temperature inversion which developed from radiational cooling.

December 19, 1976 - Sunday. Warm air advection began before sunrise and continued throughout the day causing an increase in wind speed and temperature. Skies were mostly sunny. Temperatures rose into the 50's by late afternoon. A good deal of soil drying occurred during the past two days. The first campaign ended at 8:00 PM Sunday evening.

Campaign II
2000 January 5 -
2000 January 7, 1977

January 5, 1977 - Wednesday. Variable cloudiness and cold temperatures were the agenda for the day. Snow depth of about six inches covered most of the study area. However there had been some earlier drifting of snow thus leaving some areas exposed, especially within the grounds of the power plant. Temperatures rose to a tropical 15°. Skies were partially overcast during the night.

January 6, 1977 - Thursday. It continued very cold today and skies became increasingly overcast with a threat of precipitation appearing in the west horizon by darkness. Temperatures, however, rose to about freezing. Snow began at 7:00 PM and persisted through the night.

January 7, 1977 - Friday. Snow continued to fall steadily to about 9:00 AM. About five inches had fallen during the night. A period of snow squalls occurred during the late morning and early afternoon hours. Winds were very strong, gusting to about 40 mph throughout the daylight hours and causing blowing and drafting of snow. Temperatures dropped to 15° by evening. Campaign II came to an end at 8:00 PM.

Campaign III
2000 April 5 -
2000 April 7, 1977

April 5, 1977 - Tuesday. Rain which fell during the previous two days created saturated soil conditions. Soil evaporation occurred this day associated with partly cloudy skies through late afternoon. Temperatures were unseasonably cold reaching to only 44°F. Showers changing to snow flurries began in the late afternoon. Snow flurries and snow squalls continued through the night.

April 6, 1977 - Wednesday. A snow blanket of about one inch covered the ground during the morning hours. Heavy snow squalls lasting 5-30 minutes accompanied by strong gusty winds persisted throughout the day. Intervals of sunshine melted any accumulation of snow resulting from the snow squall. Flurries continued into the night.

April 7, 1977 - Thursday. Clear skies gave way to cloudy conditions by late morning. Temperatures were slightly above freezing. Showers began around noon and persisted to the early evening hours. Winds continued to be gusty as it had been throughout the monitoring period. Campaign III ended at 8:00 PM this evening.

A Comparison of Meteorological Conditions and Hi-Vol Readings

Shown in Table 4 are the mass weight concentrations of each hi-vol site for each monitoring campaign. Notice that some of the sites (Nos. 2, 3, 4, 5, and 8) collected 12-hour samples while the other sites (Nos. 6, 7, 9, and 10) collected 24-hour samples. The 12-hour samples were intended to show diurnal variations in particle loading. Displayed in Tables 1-3 are the hourly wind directions and wind speed averages for the corresponding time periods. Using the observed fugitive dust concentrations, the hourly wind direction and speed averages and the general weather and soil conditions, a qualitative comparison was made to identify the relationships between existing weather conditions and mass concentration.

Campaign I - 2000 December 17 - 2000 December 19, 1976

2000 December 17 - 0800 December 18, 1976. The first campaign was conducted over a weekend during off-peak hours when both loading and construction activities were low. The direction of the wind during the first 12-hour period fluctuated between 260° (WSW) and 330° (NW). The dominant wind direction (290° - WNW) and an average wind speed of 6.0 mph were inducive in causing the greatest loading at Site No. 2 (substation). The substation was directly in line for the largest amount of deposition from

2 OF 6

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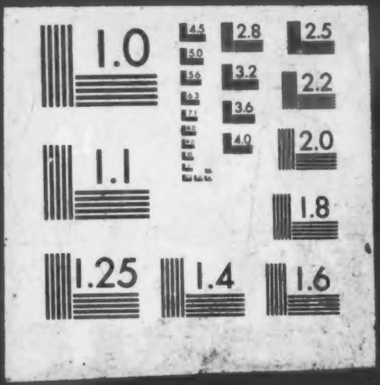
1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

the coal pile. The remaining sites were either further downwind from the sources or were significantly displaced from a direct impact of fallout.

0800 December 18 - 2000 December 18, 1976 (24-Hour Stations). Since the winds were primarily from the W and NW during the first 24 hours of this campaign, only the 24-hour sampling station, No. 7, southeast of the power plant showed significant concentration (64 $\mu g/m^3$) of fugitive dust (Nos. 6 and 9).

0800 December 18 - 2000 December 18, 1976 (12-Hour Stations). Drier soil conditions lead to higher 12-hour readings during the 0800-2000 hour period. Site No. 3 collected the largest amount, 87 $\mu g/m^3$. Winds fluctuated with a greater frequency than the previous 12 hours blowing more from the NW. Thus, except for Site No. 3, all of the hi-vols. received a minimal impact of fugitive dust.

2000 December 18 - 0800 December 19, 1976. Weather conditions were extremely calm. The wind was light and variable during the night, thus resulting in similar mass readings at all the 12-hour hi-vol. stations. The range of fugitive dust concentration was from 60 $\mu g/m^3$ at Site No. 2 near the coal pile to 75 $\mu g/m^3$ at Site No. 4.

0800 December 19 - 2000 December 19, 1976 (24-Hour Stations). In the absence of any precipitation and with an increase in wind speeds to an average of 12 mph during the second 12 hours, surface conditions continued to dry. This lead to higher readings at all 24-hour stations (Nos. 6, 7, and 10).

0800 December 19 - 2000 December 19, 1976 (12-Hour Stations). The soil continued to dry aided by a noticeable increase in wind speeds blowing from the southwest (235°). As in the first 12 hours of this campaign, Site No. 2 collected the greatest amount (306 $\mu g/m^3$). The wind direction for both the first and this last 12 hours of Campaign I was from the SW. Wind speeds were greater this 12 hours, therefore causing a larger concentration. The coal pile a few hundred feet to the southwest of Site No. 2 is the primary source of coal dust at Site No. 2. Considering its proximity to the ash disposal area, a rather small amount (45 $\mu g/m^3$) was collected at Site No. 5. This may simply be due to the fact that the ash's content is higher in moisture and therefore less disturbed by the action of the wind. Site No. 4 received a mass concentration of 100 $\mu g/m^3$.

Campaign II - 2000 January 5 - 2000 January 7, 1977

Stable atmospheric conditions resulted in light winds and variable wind directions. Under these conditions it becomes difficult to assess the source or sources responsible for contributing dust to the hi-vol. samplers. The highest reading (106 $\mu g/m^3$) was recorded at Site No. 5 located northwest of the power plant.

0800 January 6 - 2000 January 6, 1977 (24-Hour Stations). The same weather conditions that occurred in Campaign I (calm night followed by increase in wind speeds from the SW the following day) resulted in a rather high particulate concentration at Site No. 7 (110 $\mu g/m^3$). The principal source of fugitive dust may be due to general construction activities in the area and to a parking lot located SW of Site No. 7. Since weather conditions were quite calm during the first 12 hours, Sites Nos. 6 and 10 may have collected more than a background reading.

0800 January 6 - 2000 January 6, 1977 (12-Hour Stations). As in the previous campaign, a southwest wind again led to high readings at Sites No. 1 (136 $\mu g/m^3$), No. 2 (230 $\mu g/m^3$), No. 3 (189 $\mu g/m^3$), and No. 8 (115 $\mu g/m^3$). The coal pile has a direct effect on Site No. 2 when the wind is from the WSW. General dusty conditions around Site No. 2 could also be adding a rather large amount to Site No. 2. Site No. 1 is directly downwind of the coal pile under a SW wind and therefore is the likely source of coal dust. The construction activity at the coal cleaning facility and the dusty surface conditions in that area appear to be the major sources of fugitive dust to Site No. 3. The relatively high reading at Site No. 8, which is well removed from the center of the power plant operation to the SE, would be indicative of a transport of fugitive dust from the power plant area.

2000 January 6 - 0800 January 7, 1977. Snow fell throughout the entire 12-hour period. Thus all the readings were as expected, low ranging from 43 to 63 $\mu g/m^3$.

0800 January 7 - 2000 January 7, 1977 (24-Hour Stations). Readings at all of these sites were low as expected due to the accumulation of four inches of snow during the previous night.

0800 January 7 - 2000 January 7, 1977 (12-Hour Stations). Although the winds were frequently gusty from the NW, the readings were low at Sites Nos. 1, 4, 5, and 8. These sites were not downwind of any major source. However, hi-volume sampler No. 2 recorded a mass concentration of 294 $\mu g/m^3$. The coal pile is the obvious source of fugitive dust. The gusty winds had exposed large portions of coal that had snow accumulated on top of it the previous night.

Campaign III - 2000 April 5 - 2000 April 7, 1977

Fugitive dust concentrations throughout the entirety of this campaign were high at hi-vol. Nos. 1, 2, 3, 4, and 8. Winds from the SW, W, and WNW averaged 12-20 mph with gusts up to 50 mph. The prevailing wind direction was at 270°, West. The mass concentrations result again illustrates that a southwest-west wind produces high concentrations at all the monitoring sites (Sites Nos. 1, 2, 3, 4, 5, and 8) located in and around the plant operations. The data collected at Site No. 5 again indicated that the ash disposal area is not a major source of fugitive dust during winter and spring weather conditions. It may become one where an extensive period of dryness occurs. All of the 24-hour samples including No. 7 collected small amounts of fugitive dust. Site No. 6 received small amounts of fugitive dust throughout this campaign and acts as a background sampler when the wind is from the NW, W and SW. Data (concentrations low) collected at Sites Nos. 9 and 10 showed that the dust (coal, ash, etc.) airborne from the plant operations impacts before reaching these sites.

DIFFUSION MODELING

Description of Model and Modeling Approach

Battelle's Fugitive Dust Emission Model[1] is based on U.S. EPA's Multiple Point Source Model (PTMTP).[2] It predicts hourly mass concentrations of fugitive dust at any number of downwind distances. Several major alterations were made to EPA's PTMTP.

First, sources of fugitive dust were treated as area sources due to the dimensions of the area occupied by these types of sources. For example, the dimensions of the coal pile are 1.36 km x .6 km or 21.5 acres. To consider each source as an area source, the concept of a virtual point source was programmed in the model.[3] This assumes that the area sources are squared and required the user to input the length of one side. In the study at the power plant, each fugitive dust source was subdivided into smaller area sources approximately square in configuration.

To mathematically permit the deposition of fugitive dust particles, a simple particle deposition function was incorporated in the model. The amount of material deposited on a receptor location is a function of wind speed, emission rate, particle size, and distance. As wind speed increases more dust becomes entrained in the surface circulation (i.e., emission rate increases) thus creating a greater likelihood for a large amount of dust deposition. The smaller the size of the particles released into the wind, the further downwind they will be transported before settling to the ground. The range of distances where the maximum amount of fallout will occur is obviously dependent on the wind speed and particle size.

The particle deposition function (Vx/u) was programmed in the model as a distance. V, the settling velocity, was assigned a velocity which reflected a range of particle sizes. In the modeling work at the power plant, it was assumed that most of the particles released from fugitive sources were greater than 30 microns in diameter. The deposition function was applied to all receptor distances and the resulting value was assigned to receptor height. This approach effectively increased receptor heights at all downwind distances for a flat terrain. By defining a deposition function in this manner, one does not have to manipulate plume centerline calculations, which coincidentally is normally not relevant where dealing with coal storage and coal refuse sources. The height of the local terrain is then added to the height determined by the deposition function.

A third modification of EPA's PTMTP involved the formulation of an emission rate rather than a direct input of emissions for each fugitive dust source. First approximations of emission rates for each of the sources in the study area were based on an article written by S. L. Vekris, M.Sc., and published in the Ontario Hydro Research quarterly.[4] The study on dispersion of coal particles from a storage pile was conducted at the Lakeview Generating Station on the north shore of Lake Ontario. Mr. Vekris found that for a coal pile covering 40 acres and extending from 0 to 30 meters above the ground, an emission rate of 50 grams per second was reasonable to assume in modeling work for particles greater than 30 microns in size.

Subsequently, a constant was calculated which expressed the ratio of the acreage occupied by each source of fugitive dust at the Appalachian power station to the acreage of the coal pile at the Lakeview Generating Station. The value of this ratio is then multiplied in the emission rate equation by the square of the wind speed. The amount of dust released whether it originated from a coal, ash, or terrestrial source, has been programmed to be directly proportional to the amount of energy imparted by the wind or the wind speed squared.

Finally, a constant, K, was formulated in the emission rate equation which is used after the first computer run in estimating the emission rate for all of the sources. The constant represents the value of the slope of the regression line. The general form of the emission rate equation is

$$Q = K \times u^2 \times \frac{\text{Area (acres)}}{\text{40 acres}}$$

Additional modifications to EPA's PTMTP included the elimination of the plume rise routine. It was assumed that none of the sources of fugitive dust considered in this study imparted any thermal buoyancy to the airborne particles.

Methodology of Determining Coefficient of Emission

To determine the value of the coefficient of emission, formulated in the emission model and discussed in a previous section, a linear regression analysis was performed using the observed data and the model's first approximations. A linear regression analysis is a statistical method which correlates one variable to another. It involves the theory of the minimization of the sum of least squares.

If it is assumed that a straight line approximately describes the observed data to the models predictions the observed concentration, then this relationship takes the following form and is commonly referred to as the line of regression;

$$Y = a + bx$$

where a and b represent the intercept and slope, respectively. In determining the values of a and b, it becomes necessary to decide which line best describes the observed data and model first approximations. The principle of least squares aids in calculating the values of the intercept, a, and the slope, b. It states that the line of best fit to a series of values is that line about which the sum of the squares of the deviations (the difference between the line and the actual values) is a minimum.

The results of the sum of least squares is given in the following form of the line of regression:

$$P = 59.5 + 1.47\,x$$

The value of the slope of the line, 1.47, now becomes the value of the coefficient of emission, K. This value was substituted into the emission rate equation and the results of Battelle's Fugitive Dust Emissions Model are shown in Figure 2. A line that best fits the predicted vs observed data has been drawn.

Possible Causes of Scattering About Regression Line

The graph displayed in Figure 2 shows a significant amount of scatter about the line of regression. Several reasons could be attributed to this fact.

First, a number of sources were not included in the modeling work due to the nature of the sources. These include dust generated by construction activities, dust generated by vehicular traffic and parking lots, and several storage silos which dump granulated coal onto the coal storage pile. After careful examination of the observed data and the model's predictions, it is believed that all of these sources plus the general dusty surfaces of the plant are contributing in some instances significant amounts of dust.

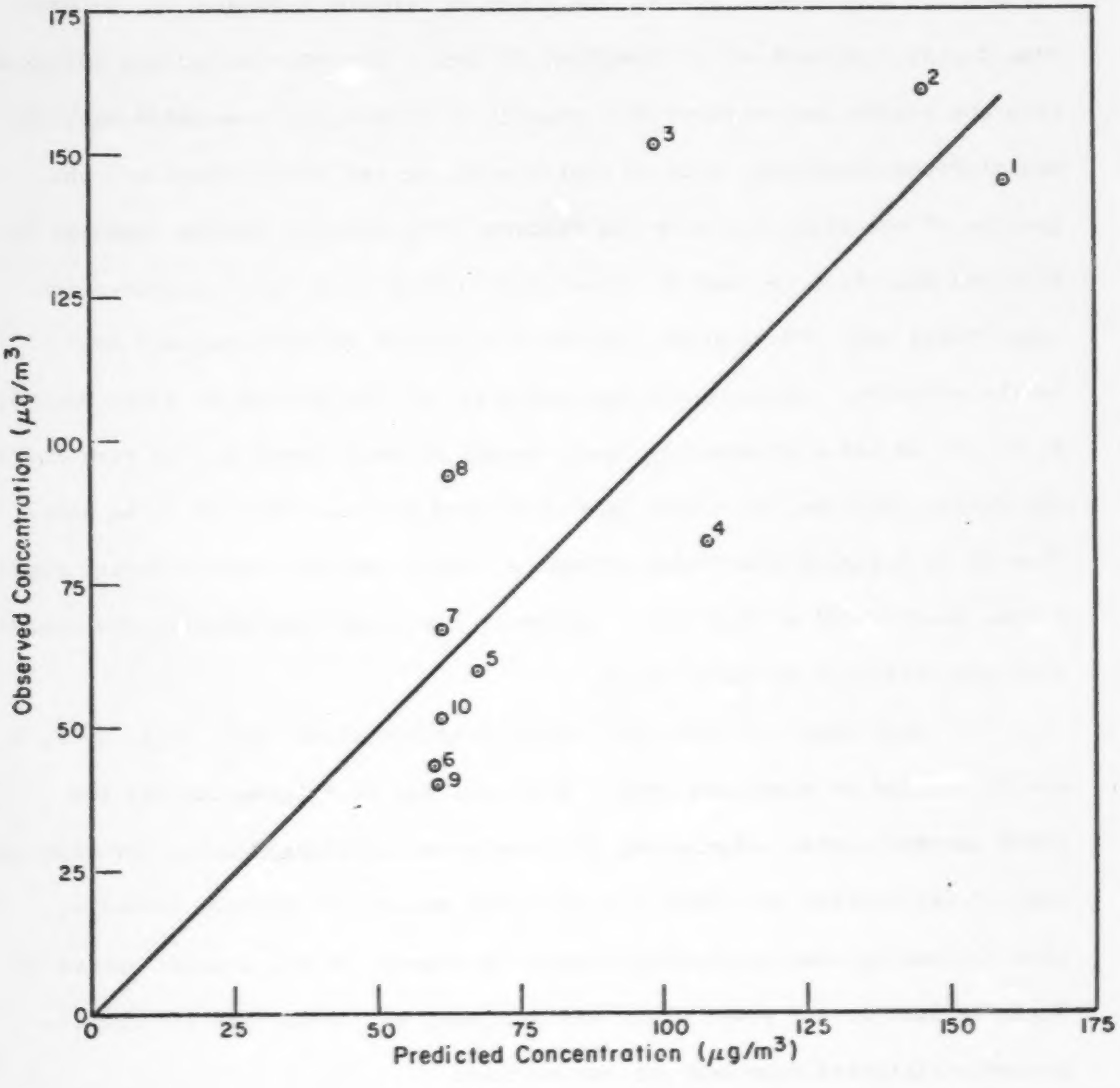

FIGURE 2. RESULTS OF LINEAR REGRESSION ANALYSIS (PREDICTED VS OBSERVED)

Second, in addition to these sources, stack emissions are also believed to have made a substantial contribution to several of the monitoring sites. Tables 9 and 10 show the results of an optical review of the sampling filters for Campaigns I and II. On numerous occasions there were at least some deposits of soot on the sampling filters. The soot either was released from the stacks, was emitted as a product of combustion associated with the diesel-fired equipment, such as coal trucks, or was re-entrained off the grounds of the plant and onto the filters. For example, during Campaign II at Sites Nos. 5, 6, 9, and 10 almost half of the total mass concentration constituted ash. It is highly unlikely to expect the ash disposal area to be the principal source of the ash since all of the filters at Sites Nos. 5, 6, 9, and 10 had a moderate to large amount of soot deposits. In particular, one filter (Site No. 10 - Wed. 2000-2000, 1-5-77) was reported to be sooty. Thus it is believed that stack emissions, under certain meteorological conditions, contributed a significant amount to the total mass particulate concentrations collected at these sites.

Soot deposits were also reported at the sites (Nos. 1, 2, 3, 4, 7, and 8) located on plant property. Here soot may be originating off the plant grounds and/or originating from vehicular traffic. Notice too that on none of the filters was there a significant amount of tertiary deposits, thus indicating that construction dust, in itself, it not a major source of fugitive dust at the power plant and that most of the dust on the plant's grounds originated from coal or ash sources.

In conclusion, there appears to be some impaction of stack emissions onto several of the monitoring sites, particularly on Sites Nos. 9 and 10, Data for the stack parameters and stack emissions were not available during the study period and therefore analysis of stack emissions was not included

TABLE 9. RESULTS OF OPTICAL EXAMINATION OF FILTER PADS CAMPAIGN I

Location Time/Date	**Coal %**	**Ash %**	Coal Particle Size **(microns)**
1, Fri-2000 12-17-76	**0-20**	**trace**	**10-40**
1, Sat-0800 12-18-76	**0-20**	**>trace**	**< 5-30**
1, Sat-2000 12-18-76	**0-20**	**>trace**	**< 5-20**
1, Sun-0800 12-19-76	**0-20**	**>trace**	**< 5-30/40**
2, Fri-2000 12-17-76	**0-20 (high side)**	**>trace**	**5-30**
2, Sat-0800 12-18-76	**0-20**	**>trace**	**5-40**
2, Sat-2000 12-18-76	**0-20 (low side)**	**1**	**< 5-20**
2, Sun-0800 12-19-76	**0-20**	**> 1**	**< 5-30**
3, Fri-2000 12-17-76	**0-20**	**trace**	**< 5-60/70**
3, Sat-0800 12-18-76	**0-20**	**0.5-1**	**5-40**
3, Sat-2000 12-18-76	**0-20**	**1**	**5-30**
3, Sun-0800 12-19-76	**0-20**	**trace**	**< 5-30**

TABLE 9. (Continued)

Location Time/Date	Coal %	Ash %	Coal Particle Size (microns)
4, Fri-2000 12-17-76	0-20 (low side)	1-2	5-20
4, Sat-0800 12-18-76	0-20 (low side)	2-3	5-20
4, Sat-2000 12-18-76	0-20 (low side)	1-2	5-20
4, Sun-0800 12-19-76	0-20 (high side)	< 1	5-40
5, Fri-2000 12-17-76	< 1-2	0-20 (low to med)	5-10
5, Sat-0800 12-18-76	< 1-2	0-20 (low to med)	5-20
5, Sat-2000 12-18-76	2-3	0-20 (low to med)	5-15
5, Sun-0800 12-19-76	1-2	0-20 (low to med)	5-15
6, Fri-2000 12-17-76	1-2	0-20 L to M	5-15
6, Sat-2000 12-18-76	1-2	0-20 (med to high)	5-15
7, Fri-2000 12-17-76	1-3	0-20 M to H	5-20
7, Sat-2000 12-18-76	0-20 L-M	0-20 L-M	5-40
8, Fri-2000 12-17-76	1	0-20 L-M	5-15
8, Sat-0800 12-18-76	trace	0-20 L-M	5-15

TABLE 9. (Continued)

Location Time/Date	Coal %	Ash %	Coal Particle Size (microns)
8, Sat-2000 12-18-76	1-2	20-40 (low to med)	5-15
8, Sun-0800 12-19-76	< 1	0-20 (high side)	5-15
9, Fri-2000 12-17-76	< 1	0-20 (high side)	5-15/20
10, Fri-2000 12-17-76	< 1	0-20 (high side)	5-20
10, Sat-2000 12-18-76	> 1	20-40 (low side)	5-15/20

TABLE 10. RESULTS OF OPTICAL EXAMINATION OF FILTER PADS CAMPAIGN II

Location Time/Date	Coal %*	Ash %	Tertiary %	Average Coal Size (Microns) Range	Remarks (Under Polarized Light/Dark Field)
#1-Pump House Wed. 2000-0800 1-5-77	0-10	<1	Trace	<5,20-30	
#1 Thurs. 0800-2000 1-6-77	0-10	<1	Trace	<5,30-40 (some 100)	
#1 Thurs. 2000-0800 1-6-77	0-10	<1	Trace	<5,10-20 (some 40&50)	
#1 Fri. 0800-2000 1-7-77	0-10	<1	Trace	5-10-30 (some 40&50)	Soot.
#2-Substation Wed. 2000-0800 1-5-88	0-10	<1	Trace	<5,10-20 (few larger)	Soot.
#2 Thurs. 0800-2000 1-6-77	10-20 Low Side <15	1-2	Trace	<5,10-20 (some larger)	Soot.
#2 Thurs. 200-0800 1-6-77	0-10	2-3	Trace	<5,10-30 (few larger)	Soot.
#2 Fri. 0800-2000 1-7-77	10-20	<1	Trace	<5,10-30 (some larger)	
#3 - On-site Trailer Wed. 2000-0800 1-5-77	0-10	<1	Trace	<5,10-30 (some larger)	Soot.
#3 Thurs. 0800-2000 1-6-77	0-10 Hi Side >7	<1	Trace	<5,10-30	Soot.
#3 Thurs. 2000-0800 1-6-77	0-10	<1	Trace	5,20-30 (some larger) (ones, ~100)	Soot.
#3 Fri. 0900-2000 1/7/77	0-10	<1	Trace	<5-70	Soot.
#4 Mobile Van Wed. 2000-0800 1-5-77	0-10	~1	Trace	<5-30	Soot.
#4 Thurs. 0800-2000 1-6-77	0-10	<1	Trace	<5-30 (some larger) (ones, ~60)	Some soot.
#4 Thurs. 2000-0800 1-6-77	0-10	<1	Trace	<5-30 (some larger)	Some soot.
#4 Fri. 0800-2000 1-7-77	0-10	<1	Trace	<5-30-40	Very little soot.

TABLE 10. (Continued)

Location Time/Date	Coal %*	Ash %	Tertiary %	Average Coal Size (Microns) Range	Remarks (Under Polarized Light/Dark Field)
#5 - Ash Disposal Wed. 2000-0800 1-5-77	0-10	1-2	Trace	<5, 30 (some larger)	Soot.
#5 Thurs. 0800-2000 1-6-77	0-10	<1	Trace	<5-30-40	Some soot.
#5 Thurs. 2000-0800 1-6-77	0-10	<1	Trace	<5-20	Some soot.
#5 Fri. 0800-2000 1-7-77	0-10 Low Side <5	<5	Trace	<5-20 (some larger)	Some soot.
#6 Schirf Farm ** Wed. 2000-2000 1-5-77	0-10 Low <5	<1	Trace	<5-40 (some larger)	Soot.
#6 Thurs. 2000-2000 1-6-77	0-10 Low <5	<1	Trace	<5-20 (few larger)	Soot.
#7 Unit #3 ** Wed. 2000-2000 1-5-77	0-10	1-2	Trace	<5-30	Very sooty.
#7 Thurs. 2000-2000 1-6-77	0-10	~1	Trace	<5-30	Soot.
#8 Refuse Coal Area Wed. 2000-0800 1-5-77	0-10 Low <5	<1	Trace	<5-10-20	Soot.
#8 ** Thurs. 0800-2000 1-6-77	0-10	1-2	Trace	<5-20	Soot.
#8 Thurs. 2000-0800 1-6-77	0-10 Low <5	<1	Trace	<5-30 (few larger) (ones 70)	Soot.
#8 Fri. 0800-2000 1-7-77	0-10	1	Trace	<5-30 (few larger)	Some soot.
#9 Recreation Area ** Sat. 2000-0800 12-18-76	0-10 Low <5	3-4	Trace	<5-10-15	Soot.
#9 ** Wed. 2000-2000 1-5-77	0-10 Low <5	1-2	Trace	<5-20	Soot.
#9 Thurs. 2000-2000 1-6-77	0-10 Low <5	2-3	Trace	<5-10	Soot.
#10 Stiles Farm** Wed. 2000-2000 1-5-77	0-10 Low <5	5-10	Trace	<5-10-15	Very sooty.
#10 Thurs. 2000 1-5-77	0-10 Low <5	5-10	Trace	<5-20	Soot.

* % Reported is based upon an area/grid impact or % area of available filter pad.
** Filter forwarded for chemical analysis.

in the diffusion modeling. Therefore, a small percentage of the scattering about the line of regression can be attributed to stack emissions.

A third reason for the scatter about the line of regression can be attributed to the method used in averaging hourly wind direction and wind speed data. During a given hour the direction of the wind may and did fluctuate quite severely. It is difficult to include these fluctuations when representing the wind directions for a given hour with a single value. To remedy this, wind direction data will be averaged over fifteen-minute intervals in future studies.

The model, as expected, is quite sensitive to wind speed. At wind speeds less than approximately 3 mph the model predicts a very small amount of dust deposition. However, except for residual dust left in the air from operations made during windy conditions, one would expect that contributions of dust during calm wind conditions from fugitive dust sources would be minimal.

The model was quite effective in predicting concentrations during windy conditions. As the wind speed increases the model becomes more successful. A listing of the model's strengths and weaknesses is summarized below. Some of the model's weaknesses are inherited from the base model (EPA-PTMTP) and are common to nearly all Gaussian-type diffusion models.

1. The model's capability in predicting dust concentrations is sensitive to wind direction. Wind direction sector averaging is not included in the model's make-up and therefore it becomes extremely important to give more consideration to wind directions that occur with higher wind speeds than those with lower wind speeds.

2. The model is very sensitive to wind speed. For low wind speeds, it predicts extremely low concentrations. However, when dealing with fugitive dust sources, one expects the amount of airborne particles to be insignificant during calm wind conditions.
3. The spread of the plume of dust vertically and horizontally from a storage pile may not in fact be reasonably described by the Gaussian distribution.
4. The model is quite reliable in predicting concentrations associated with windy surface conditions. It's reliability increases with increasing wind speed.
5. The model is better able to preduct long-term averages (i.e., 24 hours and greater) than short-term averages (12-hour averages and less).

CONCLUSIONS

The overall objective of this study was to identify fugitive dust sources and quantify the particulate emissions from these sources.

The maximum mass concentrations were observed at Sites 1, 2, and 3. These sites are located at distances from 150 to 200 meters from the coal pile. The extent of a significant fugitive dust impast was measured as far downwind as Site No. 8, which was approximately 1200 meters from the coal pile. Generally, heaviest concentrations occurred during 0800-2000 hour sampling period. During much of the sampling period in Campaign II the ground was covered with snow, and measurements were recorded over 100 $\mu g/m^3$ and coal particles were observed on the snow by the investigators of this study. Of the 24-hour sampling stations, a maximum concentration of 110 $\mu g/m^3$ was measured at Site No. 7. This site was located approximately 500 meters south upwind from the coal pile and adjacent to an unpaved employee parking lot, which probably contributed to the mass loading of this site. There was one valid measurement conducted using the particle sizing sampler. Approximately 44 percent of the particles were in the 0 - 1.1 micron range.

The microscropic analysis of the filter pads concluded that the majority of coal particles were observed in 5 - 70 micron range while the majority of the ash particles were observed in the 5 - 20 micron range. Also, the analysis indicated the coal was the dominant particle on the majority of the pads.

The chemical analysis indicates that beryllium, vanadium, and antimony were not observed at any of the monitoring sites and titanium was observed at two sites (1 and 2).

This study indicates that trace element concentrations are not always directly proportional to the mass loading of the filters, i.e., the maximum observed concentration for nickel was reported on a filter that weighed between 0 - 50 μg/m^3 and the maximum concentrations for cadmium and lead were reported on filters that weighed between 51 - 100 μg/m^3. The minimum reported value for cadmium was observed on a filter that weighed between 251 - 300 μg/m^3. Lead appears to have high levels of ambient concentrations. This may be attributed to the large amount of vehicular traffic in the area. The average trace element concentrations were higher at 12-hour sampling sites with the exception of arsenic, where the average concentration of the 12-hour site was .015 μg/m^3, while the average concentration of the 24-hour site was .013 μg/m^3.

To conclude some of the more important observations of weather conditions and its relationship with observed sampling data, a listing is given below:

(1) Precipitation in the form of rain or snow occurred during 4 of the 6 sampling days.

(2) Southwest winds, the prevailing wind direction in this Appalachian area, occurred with the highest frequency (0.7 or 70%) during the three monitoring campaigns. Fugitive dust concentrations at most of the sampling sites observed with southwest winds were higher than those associated with any of the other observed wind conditions.

(3) On two of the six sampling nights, weather conditions were extremely stable characterized by low wind speeds (<2 mph) and variable wind direction. Under these conditions, stack emissions are believed to have

contributed to total mass concentrations collected at Sites Nos. 5, 8, 9, and 10. Total mass concentrations were similar at the sites during calm weather conditions.

(4) Low fugitive dust readings were observed with northwest winds at all sampling sites except at Site No. 2. The coal pile is a major source at Site No. 2 when the wind is from the NW.

(5) The ash disposal area was not a principal source of fugitive dust. This is probably due to the moisture content of the ash in situ.

(6) The coal pile was the primary source of coal dust collected at sampling sites No. 1 and 2.

(7) Where the wind blew from the NW, W, and SW, which occurred 80% of the time, sampling data collected at Site No. 6 are of background nature. Except for one 24-hour period, total mass concentrations observed at Site No. 6 ranged from 33-47 $\mu g/m^3$.

(8) The general dusty surfaces of the plant grounds are a significant source of coal and ash dust collected at all sites located around plant operations and especially at Site No. 3. The dust lying on plant ground is believed to have derived from the coal pile, mining operations and possibly the stacks.

(9) Vehicular traffic around the plant also appears to have made a significant contribution to some of the

sampling sites.

In addition to the above conclusions, below is a summary listing of a number of reasons for the scattering in the diffusion model's predictions.

(1) A number of sources were not incorporated into the diffusion modeling due to the nature of the sources. These included dust generated by vehicular traffic, parking lots, construction activities, several storage silos, and especially the general dusty surface of the plant grounds.

(2) Data for power plant stack emissions were not available during the study period. Thus, an analysis of stack emissions was not incorporated in the diffusion modeling.

(3) Averaging wind direction data over a given hour will cause inconsistencies in the model's prediction during variable wind conditions. For future studies, wind direction data will be averaged over fifteen-minute intervals or perhaps a smaller time interval.

Finally, a list is given below which summarizes the strengths and weaknesses of Battelle's Fugitive Dust Emission Model:

(1) The model is sensitive to wind speeds. It predicts essentially zero concentrations from fugitive dust sources at wind speeds less than 2 mph. As mentioned earlier, one expects, however, to find an insignificant amount of coal dust on hi-volume filters during calm wind conditions.

(2) The model is quite reliable in predicting concentrations of fugitive dust associated with wind surface conditions.

(3) The model is better able to predict long-term averages (i.e., 24 hours and greater) and less valuable for short-term averages (i.e., 12 hours and less).

(4) The applications of the model are best suited for use in computing fugitive dust concentrations originating from exposed storage areas (coal piles, boney piles, debris piles, etc.) associated with mining and power plant operations.

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PARTICULATE SAMPLING TECHNIQUES FOR A COKE QUENCH TOWER

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ABSTRACT:

Although pollutants from quenching coke are emitted from towers these emissions have frequently been termed fugitive due to their intermittent nature, high turbulence and moisture content makes conventional sampling approaches extremely difficult. This presentation summarizes the results of a study conducted by the Division of Stationary Source Enforcement and its contractor, York Research Corporation to determine the size of quench tower particulate emissions and methods used to sample such emissions.

In the Spring of 1976 York Research Corporation was awarded a Task Order by the Environmental Protection Agency to determine the magnitude and character of quench tower emissions with respect to quench water quality.

A common practice in this country's steel industry is the use of contaminated water to quench incandescent coke. Typically, 10 to 20 ton loads of hot (2000 + ^{o}F) coke are quenched by 6,000 to 12,000 gallons of water. Each quench takes about 2 to 3 minutes and produces huge billowing clouds of steam, water droplets, and air contaminants. In order to draft these emissions out of the work area, quenching takes place under towers which are open at the bottom to admit the coke car. Baffles are often fitted above the quench car to reduce the amount of large diameter particulates emitted and amount of make-up water needed, by returning water not expelled from the tower back to the sump.

Previous test methodologies to determine the magnitude and nature of air pollutants from quench towers were often flawed by sampling difficulties such as the exclusion of certain size particles or limited in the measurement of necessary process parameters. Early sampling attempts using greased plates (1) and petri dishes (2) measured only large diameter, heavy aerosols (droplets, solid, or both). Many pollution control engineers have theorized that significant amounts of coke plant water contaminants directed to quench tower sumps for disposal are transformed by the quenching process into air pollutants which escape the baffles.

Further attempts by state and local agencies to measure particulate emissions utilizing standard EPA sampling equipment were also limited in their scope and encountered a number of sampling difficulties. (3) (4) Major problems occurred because the short, violent, rush of steam did not allow accurate reading and adjustment of the sampling equipment to maintain isokinetic conditions (the EPA method contemplates measuring velocities and making adjustments every 3 to 5 minutes--more than the total time of the quench). Also, droplets in the exhaust stream plugged filters, and made determinations of the molecular weight of the gases nearly impossible. In addition, the short duration of the quenches made capturing the prescribed volume of gases extremely difficult. The square shape of most quench towers, and the use of internal partitions probably compounded these problems by causing uneven flows across the tower cross-section.

A main objective of this study was, therefore, to design and implement a sampling program which accurately measured particulate emissions. Table 1 lists the parameters, method of measurement and locations employed in this test program. This paper concentrates on the particulate sampling portion of the test program. In order to measure quench tower emissions in a manner that incorporated the techniques of 40 CFR, Part 60 (EPA Method 5) and that also gave reproducible results, major problems in (A) site selection, (B) sampling train configuration, and (C) sampling techniques had to be overcome.

Table 2 lists the major problems and their possible effect on the sampling results and our solutions.

A. SITE SELECTION

In order to most accurately determine the impact of water quality on quench emissions, criteria for selecting a test site included: tower configuration which would produce uniform cross-sectional flows and the ability to quench with a wide range of Total Dissolved Solids concentrations in the water. After a general survey of quench towers, a tower at U.S. Steel's Lorain Works was selected for testing. This tower was a circular brick chimney which, after the baffles, did not have internal buttressing. In addition, the facility was constructed with the ability to re-route contaminated water to other quench towers in the plant and use service water for quenching at the selected towers.

A schematic of the tower is shown in Figure 1. Tests were conducted approximately 100 feet above ground and 20 feet from the top of the tower.

B. SAMPLE TRAIN CONFIGURATION

Emission testing was conducted with a Hi-volume Aerotherm sample train to minimize the amount of time required to collect sufficient volume of gas and weight of particulate matter. (Figure 2)

In order to allow a more accurate determination of moisture in the stack gas, prevent filter plugging, and provide a rough indication of aerosol sizing, a cyclone was fitted on the front of an eleven foot probe. The cyclone was designed to have a 50% cut size of about 10 microns at anticipated flow rates. Particulate and gas were drawn through the unheated cyclone where large diameter particles and water droplets were collected. After passing through the heated (250°F) probe at about 2 cubic feet per minute and a heated (250°F) Spectrograde type AE glass fiber filter where particles larger than 0.3 microns were collected, the gas sample passed through an impinger train-ice bath assembly where additional particulate matter and some condensibles were removed. The gas was then further dried prior to entering the flow control module by means of an impinger filled with 300 grams of silica gel.

A continuous strip chart recorder was connected to a Hastings meter (see Figure 2) to record the velocity head pressure (Δ p) and to aid in verifying any uneven flow patterns. The unit operated with air continually purging the pitot lines thus preventing stack gas from entering the meter. Differential pressure across the pitot tube was measured as a change in the pneumatic bridge, formed by the velocity transducer, manifold, and pitot tube. As flow across the tip occurred a differential pressure developed, imbalanced the bridge and caused a small amount of purge gas to flow through the transducer. The transducer measured this flow which was related to the main gas flow at the tip of the pitot tube. Purge gas still exhausted through both openings, but at a slightly unequal rate. The instrument allowed accurate measurement of flow in the steam plume even though large diameter solids (coke breeze) and water droplets were present.

Preliminary Field Tests

In August 1976, a pretest survey was conducted to determine:

1. If the circular tower selected produced uniform velocities across the sampling points required by EPA Method 1.

2. If the planned sampling train modification would enable isokinetic sampling.

3. If emission results would be reproducible.

4. Procedures for the official tests.

Velocity profiles were obtained for at least two quenches at each of the required 36 points. These preliminary profiles were analyzed for each one second time interval for magnitude of Δp. The Δp's of each interval were then added together and averaged by dividing the time of each quench into the total. Visual comparison of overlaid profiles showed that roughly the same pattern, time, and velocity heads were found for each quench, suggesting that velocity heads for a particular point in the stack could be predicted.

Slopes (caused by the heat rise generated by the incandescent coke; the rising steam plume and the declining steam plume) were also analyzed to aid in obtaining sampling rate adjustments. Slopes of the initial increase in the velocity head (ramp-up) were found to approximate a 45^{o} angle. The declining slope of the profile never fell to a zero velocity pressure as the steam plume continued after the coke car exited the tower.

The three sections of the profile (Figure 3) were defined as ramp-up - from the time the car entered the tower until the time water hit the incandescent coke. (Average time 30 seconds). Plateau or middle - from the time the peak velocity was reached to the time the water spray ended (average time 60 seconds). And ramp down - from the time the water spray ended until the coke car left the tower (average time 45 seconds). From these Δp's, velocity (feet per minute) calculations were prepared utilizing moisture data obtained from the previous (3) (4) tests, results from a limited number of wet bulb-dry bulb runs and, Orsat samples obtained in accordance with EPA Method 3 with the use of two condenser units to trap entrained water droplets. In addition to the velocity traverses, initial measurements were performed with a Fecheimer probe to determine the maximum angle of flow in the tower. Data from these findings were limited but indicated that future traverses and sampling should be conducted near 110 degrees measured from the horizontal.

These were later confirmed by further testing conducted with a vane type device.

Based on this preliminary test information, it was decided to perform three tests of four quenches each at one point in the stack. In order to reflect the total quench emissions, sampling began when the quench car entered the tower and ended when it left. The purpose of these tests was to determine how many quenches would be sampled per run in the official tests and provide some indication of reproducibility and precision. Process parameters such as water quality, coke greenness, etc. were not recorded. Laboratory results from these three tests showed sufficient weights of particulate (over 100 mg)and volumes of dry stack gas (over 15 cubic feet) could be obtained from four quenches instead of the twenty or more quenches which might have been required by EPA Method 5. Variability of these tests ranged from approximately 0.7 gr/SCFD to 1.2 gr/SCFD (which was acceptably close) and isokinetic rates were within 10% of 100%.

Since the number of quenches could be reduced from twenty or more to four and flows did not vary much from point to point, the original number of tests (three to be performed at 36 points in the tower) was increased to twelve contaminated and twelve clean. This allowed statistical verification of the results and the ability to assess the impact of other variables (e.g. fugitive emissions, greenness of coke, water quality changes, wind direction...) which might be hidden by sampling a large number of quenches or by shifting from traverse point to traverse point. Based on the preliminary velocity profiles and the preliminary particulate tests, points on each axis of three rings, twelve points total, were selected as being most likely to give mass emission rates representative of the tower as a whole. See Figure 2.

(C) SAMPLING TECHNIQUE

Data from the preliminary field tests indicated that velocity head (Δp) was predictable and values for sample rates (ΔH) ramp-up, etc. could be determined based on a preliminary velocity profile taken before each test run. Data from the velocity profile was then utilized to determine:

1. Absence of erratic flow pattern(s). (If present, the test was delayed).
2. Velocity pressure (ΔP)
3. Velocity (feet per minute)
4. Required nozzle size

5. Predicted sampling rates

Test Sequence

The initial traverse was used to establish the rate (length of time) of rise of the velocity head (Δ p), the maximum Δ p, and the rate of decline of Δ p to an end point greater than zero. For each quench the sampling rate (ΔH) was gradually increased from the signal car-in to approximately 0.50 inches of water over a thirty (30) second period. This maximum sampling rate was maintained until the signal water-off was given and a ramp down procedure was initiated to a predetermined rate (approximately 0.26 inches of water) established from the averaging of the ramp down portion of the velocity profile. Sampling was terminated when the car was completely out of the tower.

RESULTS

A sampling program has been designed to avoid or overcome the hostile environment of a coke quench tower. Although a full evaluation of the thousands of data elements collected in the study is not yet complete enough analysis has been performed to conclude that:

The particulate emission tests were as

precise as, and correlatable to
Standard EPA measurement techniques.

ACKNOWLEDGEMENT

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The efforts of York Research's stack testing crew in overcoming the hostile environment of a quench tower at night are appreciated.

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PARAMETERS AND MEASUREMENT METHODS

TABLE 1

Parameter	Number of Tests and Number of Quenches	Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
A. Particulate Emission				
1. Mass and concentrations (cyclone-suspended and dissolved solids, water and acetone wash of nozzle, cyclone and probe, filter, and impingers).	44 contaminated	EPA Method 5 - modified	Method 5	(10)
2. Size distribution of particulates and water droplets.	96-10 u 2 2	Cyclone 10 u and Method 5 train Sensitized paper tests KLD probe	Coulter Counter and Chemical Composition	(10)
3. Fugitive emissions	96	Visible observation		
4. Elemental Analysis	2	Method 5 train	Spark Source Spectrometry	(10)
5. Mutagenicity	1	Method 5 train with Battelle absorber	Level I Analysis	(10)
6. High Molecular weight Hydrocarbons	Contaminated Clean 1 2 3	Method 5 train Battelle Absorber Water Sampled	Level I Analysis Level I Analysis	(10) (4-8 & 12)
Water spray on coke, Water supply, return and sump.	1	Water Sampled	Level I Analysis	(5-8-12 & 11(combined)

TABLE 1 (Continued)

Parameter	Number of Tests and Number of Quenches		Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
	Contaminated	Clean			
B. Gaseous Emission					
1. Cyanide	27	36	EPA Method 6 train modified with moisture traps	Method 6	(10)
2. Ammonia	36	36			
3. Sulfide	-	36	" " "		
4. Phenol	27	36	" " "		
5. Sulfur Dioxide	36	36			
6. Oxygen (Orsat 40)	(GFM-2)	Orsat-10	Orsat & Grab Flask	Method G.C.	
7. Carbon Dioxide (Orsat 40)	"	" "	" " " "	" "	
8. Hydrocarbon	GFM-2	-	Grab Flask Method	"	
9. Carbon Monoxide	"		" " "	"	
10. Total Volatilized Hydrocarbons (70^{o}F, 29.92 inches of mercury)					
C. Stack Flow Information					
1. Velocity Head		96	Hastings-Raydist meter		(10)
2. Flow direction		15	Vane-Fecheimer		
3. Gas temperature		40	Six thermocouples positioned approx. 15 feet apart up the tower.		
		96	Method 5 train		
D. Water Volumetric flow and mass rates					
1. Stack - large droplets		96	Cyclone		(10)
vapor and small droplets		96	Impinger assembly		
2. Spray - on to coke		90	Sonic flow meter		(8)
3. Return - to sump		32	Level of sump measurements		(11)
4. Sump - make-up			Level of sump measurements		(11)

TABLE 1 (Continued)

Parameter	Number of Tests and Number of Quenches	Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
E. Battery and Tower Processes	Contaminated Clean			
1. Battery, oven coking time	96	Information from plant data		
2. Greenness ratings	96	Visible observation		From pumphouse roof(8)
3. Oven heater temperature	96	Plant data		
4. Temperature of incandescent quenched-coke	38 12	Infrared thermometer Thermocouple		From pumphouse roof(8) Wharf area
5. Duration and sequence of quench operation	96	Noted on velocity profiles		

6. Coke Composition	Contaminated Quenched	Contaminated Incan-descent	Clean Quenched	Clean Incan-descent	Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
% Nitrogen	3	3	3	4	Samples taken from oven doors(incand.) and wharf area (quenched). Coke was placed in metal containers, sealed and shipped to Stamford, CT for analysis.	Ultimate-ASTM D3176-74 Proximate-ASTM D3172-73	oven doors wharf area
% Carbon	3	3	3	4			
% Hydrogen	3	3	3	4			
% Moisture*	1	2	-	2			
% Volatile*	1	2	-	2			
% Sulfur*	3	3	4	4			
Btu/lb.	3	3	4	4			

* Analytical results from plant data are available for 16 coke samples during clean water tests.

7. Contaminant Deposition on coke	Contaminated Quenched	Contaminated Incan-descent	Clean Quenched	Clean Incan-descent	Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
Cyanide	4	3	4	4	Samples taken from wharf area. Coke was placed in metal containers,sealed and shipped to Stamford,CT for analysis	Samples washed and solutions analyzed by EPA Standard water and waste methods	Wharf area
TOC	4	3		4			
Dissolved solids	4	3	4	4			
COD	4	3	4	4			
Phenol	4	3	4	4			
Chloride	4	3	4	4			
Calcium	4	3	4	4			
Sulfate	4	3	4	4			
Sulfide	4	3	4	4			

TABLE 1 (Continued)

Parameter	Number of Tests and Number of Quenches	Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
8. Coal		Plant data		
Volatile	18	Plant data		
Ash	18	Plant data		
Free Moisture	18	Plant data		
Sulfur	18	Plant data		
F. Ambient Conditions				
1. Wind direction, speed, dewpoint, relative humidity, temperature, and barometric pressure.	Each hour			Airport located 1.4 miles from plant.
G. Water Quality				
1. Phenol	80 contaminated 104 - clean	Composite samples taken from lines tapped into inlet header line and return trough. Make-up samples obtained by: (contaminated) bucket in open stream, (clean) service water in wharf area. Two samples taken each test day. One sample for 8 quenches.	EPA "Methods for Chemical Analysis of Water and Wastes.	Inlet-header pipe (8) Return-trough (12) Make-up-pipe (4) to sump-contaminated. (5) service water in wharf area-clean.
2. Cyanide				
3. Sulfate				
4. Sulfide				
5. Ammonia				
6. Calcium				
7. Oils				
8. Chloride				
9. COD				
10. TOC				
11. Electrical Conductivity				
12. Total Solids				
13. Dissolved solids				
14. Suspended solids				
15. Volatile solids				

TABLE 1 (Continued)

Parameter	Number of Tests and Number of Quenches	Field Measurement Method	Laboratory Analysis Method	Sampling Location (Figure 1)
II. Sump Sediment	3 samples	Weighted bucket dragged along sump bottom	EPA "Methods for Chemical Analysis of Water and Wastes"	Sump (11)
1. Conductivity				
2. TOC				
3. Phenol				
4. Total Solids				
5. Volatile Solids				
6. Sulfate				
7. Cyanide				
8. Ammonia				
9. Calcium				
10. COD				
11. Oil				
12. Chloride				

POTENTIAL PROBLEMS AND SOLUTIONS IN TESTING QUENCH TOWER EMISSIONS

TABLE 2

Potential Problems	Effect on Accuracy	Solution
Small range of TDS Concentrations	Desired a wide range (at least 3-5 multiple of concentration to show effect)	Ratio of TDS concentration at Lorain was 10:1 in the same quench tower.
Tower configuration	Square, squat, sectionalized towers are likely to produce non-uniform flow	Tall circular tower with no internal buttressing was selected.
Short duration of quench resulted in velocity profiles changing faster than could be measured or recorded by usual methods.	Velocities move up and down so rapidly as to make accuracy difficult to achieve.	Use of Hastings-Raydist velocity meter with continuous recording.
Droplets in stack sample	Inability to measure actual moisture content, molecular weight of stack gas, filter plugging.	Cyclone (50% cut size about 7-13 microns) was fitted on the front of the probe.
Droplets and grit in stack gases	Plugging of pitot tubes	Used Hastings Raydist velocity meter with continuous purge.
Fugitive emissions	Emissions exited from entrances of tower causing non-representative sampling.	Entrance emissions monitored and testing halted when excessive (longer than one minute per quench or at Project Director's discretion).
Sampling locations	Possible uneven velocity patterns throughout stack.	Performed traverse of 36 points-velocity was not affected by position.
Number of quenches	Method 5 would require sampling 20 quenches to get a one hour test, however, this would have resulted in plugging and other errors.	Pre-survey tests showed that four (4) quenches would provide sufficient weight of particulate (over 100 mg) and volumes of dry stack gas (over 15 cubic ft)using a high volume sampler.

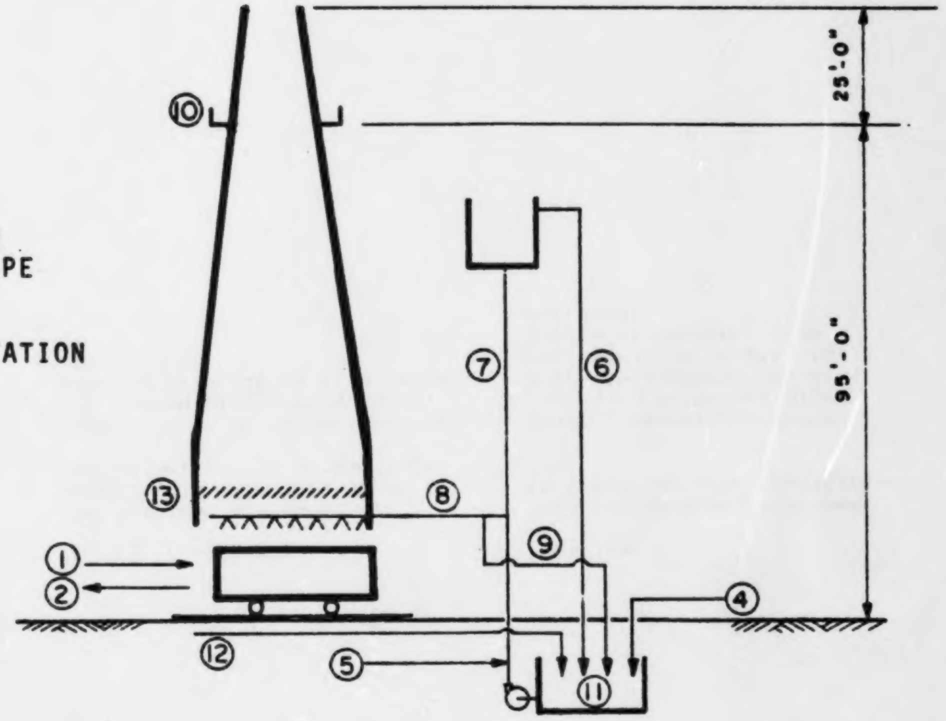
TABLE 2 (Continued)

Potential Problems	Effect on Accuracy	Solution
Skewed Flow	The vertical component of velocity is different from the velocity of a skewed flow.	Vane measurements were made to determine probe positioning.
Some water flow measurements were difficult to obtain because of the physical layout of piping and return flow ditches.	Mass balance of water flows in the quench processes were not related directly to each stack measurement.	Sonic measurements device installed on header pipe, sump level measurements performed and results for a series of quenches were averaged.

FIGURE 1

QUENCH TOWER

1	INCANDESCENT COKE
2	QUENCHED COKE
3	EXHAUST GASES
4	CONTAMINATED WATER
5	SERVICE WATER
6	HEAD TANK - OVERFLOW
7	HEAD TANK - STAND PIPE
8	NOZZLE HEADER
9	NOZZLE HEADER DRAIN
10	EMISSIONS TESTING STATION
11	SUMP
12	RETURN DRAIN DITCH
13	BAFFLES



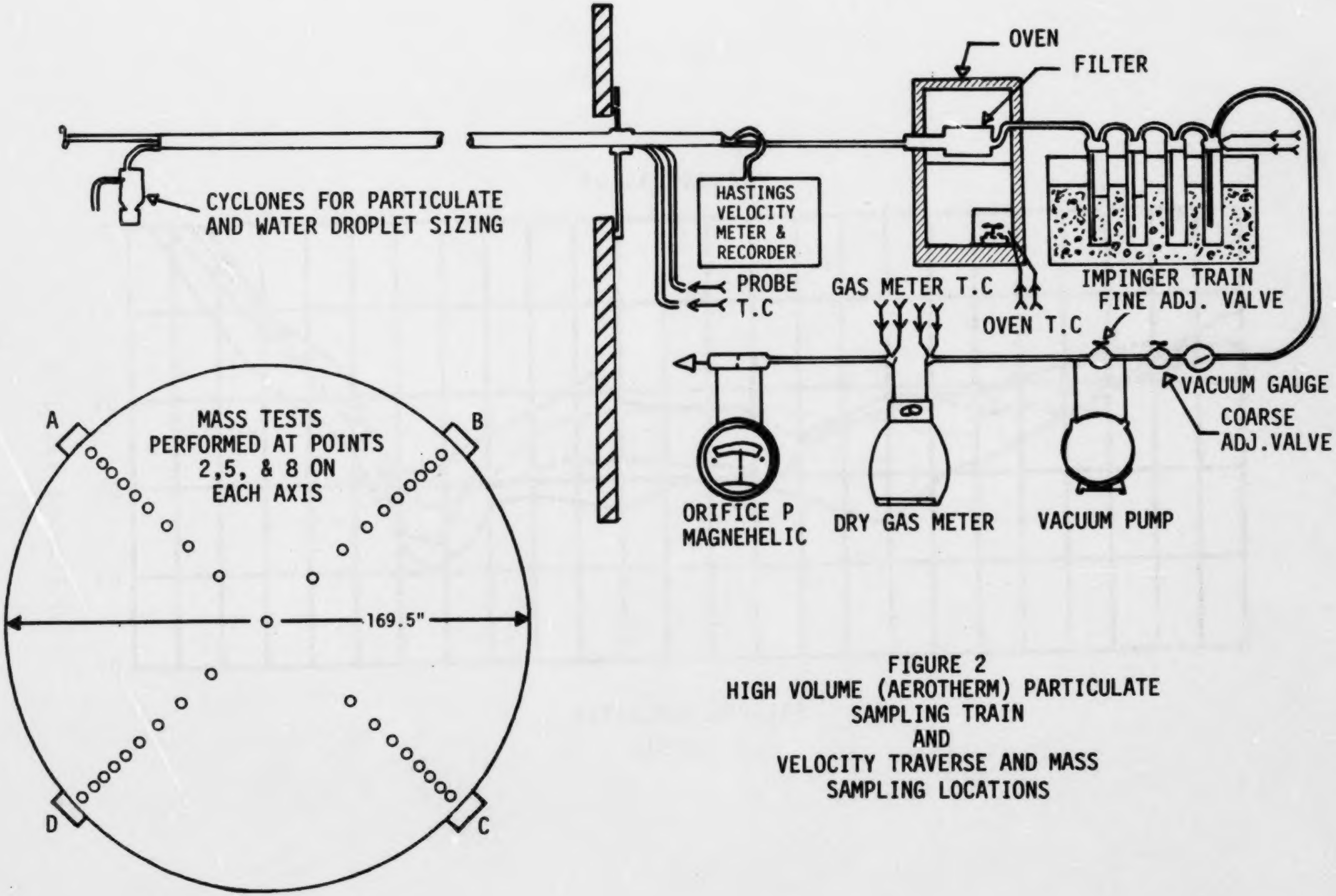

OVEN
FILTER
CYCLONES FOR PARTICULATE AND WATER DROPLET SIZING
HASTINGS VELOCITY METER & RECORDER
PROBE
T.C
GAS METER T.C
OVEN T.C
IMPINGER TRAIN
FINE ADJ. VALVE
VACUUM GAUGE
COARSE ADJ.VALVE
ORIFICE P MAGNEHELIC
DRY GAS METER
VACUUM PUMP
A
B
C
D
MASS TESTS PERFORMED AT POINTS 2,5, & 8 ON EACH AXIS
169.5"

FIGURE 2
HIGH VOLUME (AEROTHERM) PARTICULATE
SAMPLING TRAIN
AND
VELOCITY TRAVERSE AND MASS
SAMPLING LOCATIONS

FIGURE 3
VELOCITY PROFILE

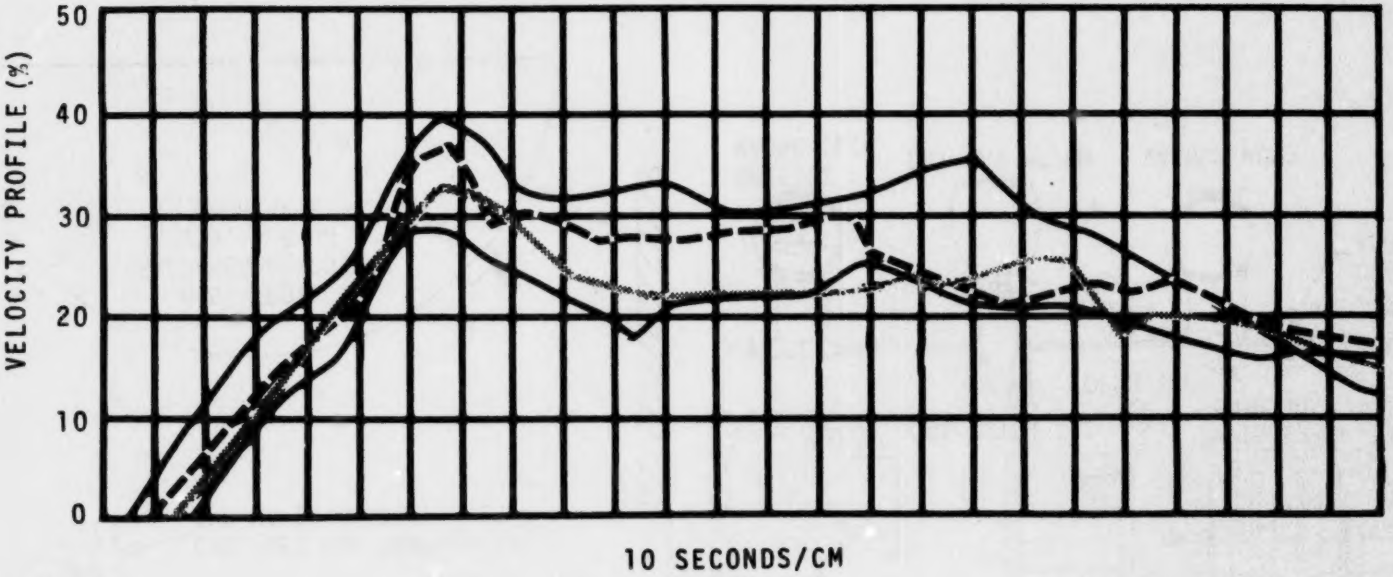
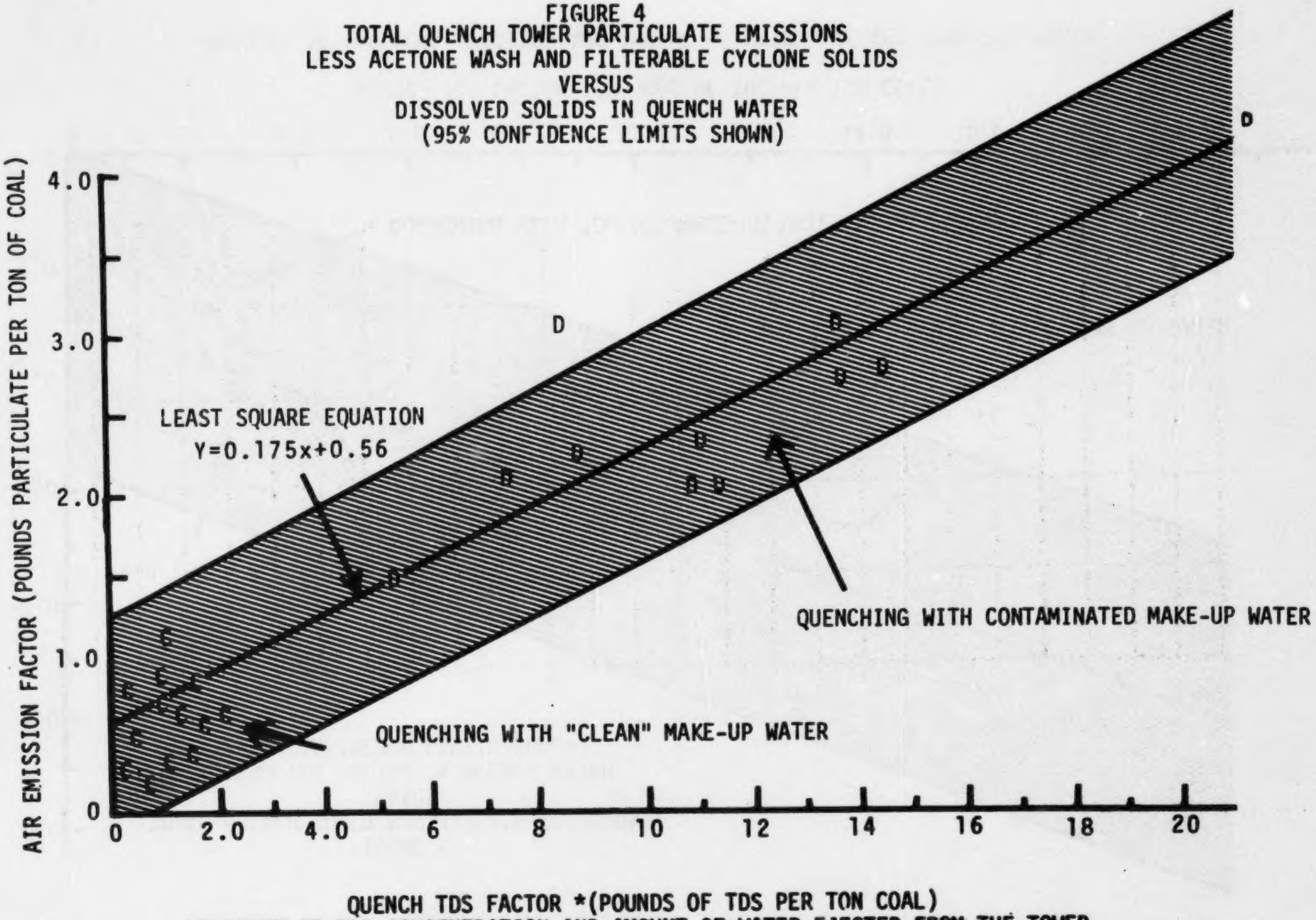
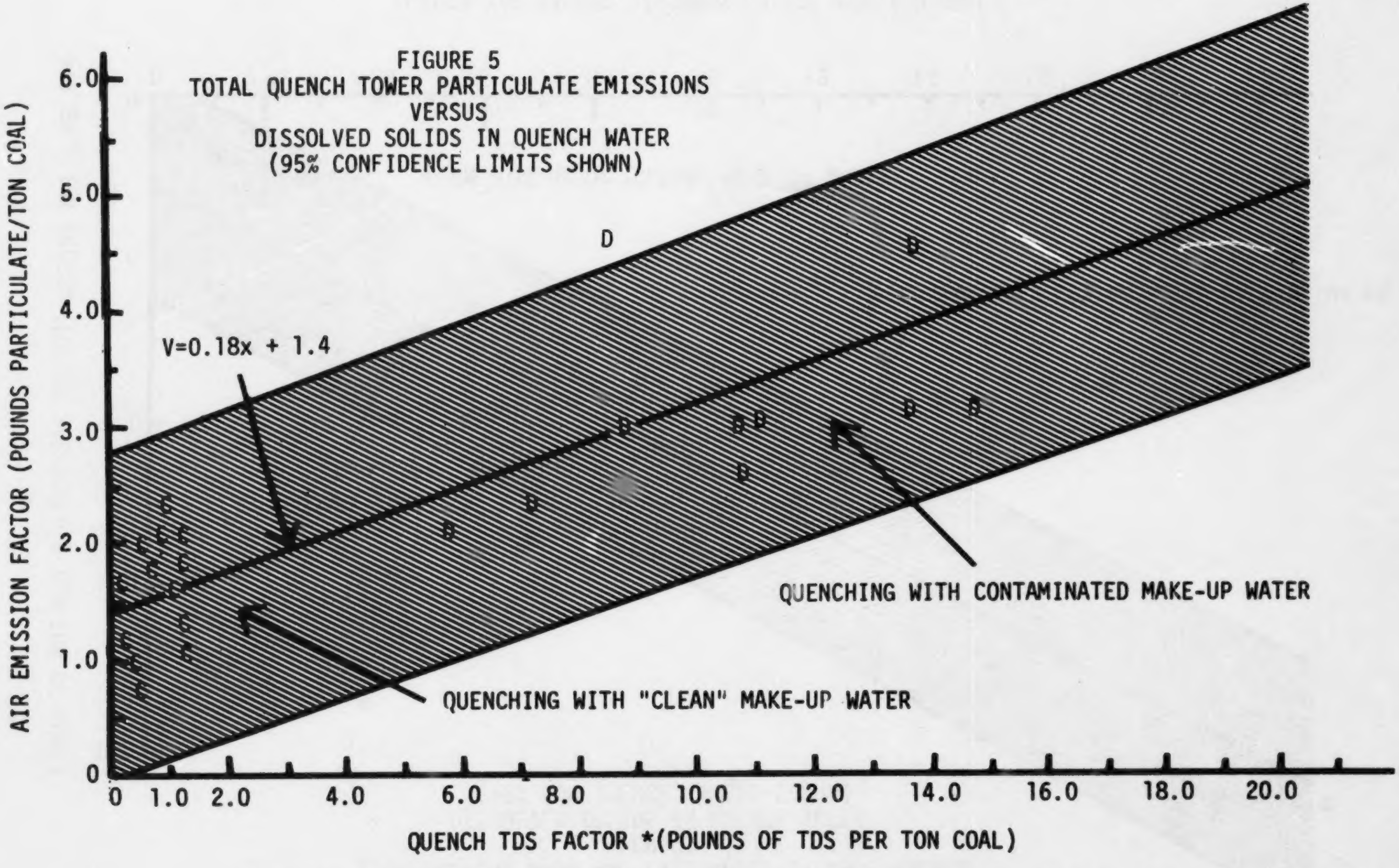


FIGURE 4
TOTAL QUENCH TOWER PARTICULATE EMISSIONS
LESS ACETONE WASH AND FILTERABLE CYCLONE SOLIDS
VERSUS
DISSOLVED SOLIDS IN QUENCH WATER
(95% CONFIDENCE LIMITS SHOWN)



*PRODUCT OF TDS CONCENTRATION AND AMOUNT OF WATER EJECTED FROM THE TOWER

FIGURE 5
TOTAL QUENCH TOWER PARTICULATE EMISSIONS
VERSUS
DISSOLVED SOLIDS IN QUENCH WATER
(95% CONFIDENCE LIMITS SHOWN)



*PRODUCT OF TDS CONCENTRATION AND AMOUNT OF WATER EJECTED FROM THE TOWER

MONITORING INDUSTRIAL FUGITIVE EMISSIONS
--AN OCCUPATIONAL HEALTH PERSPECTIVE

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ABSTRACT

Fugitive emissions from industrial processes are a primary monitoring concern of NIOSH field research investigators. The NIOSH-OSHA Standards Completion Program (SCP) has tested about 400 and validated some 200 sampling and analytical methods. In-plant worker exposures are routinely monitored and evaluated based on personal sampling (breathing zone samples) which provide 8-hour time weighted average exposure concentrations. Low volume sampling (0.010 to 2.5 ℓpm) utilizing filters, and liquid and solid sorbents are used for a variety of industrial contaminants. Many contaminants are adequately evaluated in the ppb and $\mu g/m^3$ range using existing analytical techniques employing these miniaturized sampling methods. Occupational exposure data for benzene, PCBs, asbestos, epichlorohydrin, butadiene, and styrene are presented.

INTRODUCTION

Industrial fugitive emissions constitute a continuing problem not only to environmentalists but also to the industrial hygienists as they constitute exposures to workers within the industrial plant. The use of the term "fugitive emissions" to convey the concept of pollutant discharges that enter man's environment from other than well-defined sources, such as stacks, ducts and exhausts for air pollutants or pipes, channels, and culverts for water pollutants, can also be applied to general air contaminants of concern within industrial plants. This places emphasis on the similarity of concern for these culprit pollutants resulting from industrial related operations.

Despite mutual concern with the same industrial contaminants, the overall monitoring objectives of the Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) differ. Generally, EPA has as its purpose monitoring emission rates from industrial sources and assessing the impact on the environment including man, animal, and plant life; NIOSH has as its purpose monitoring worker exposures and assessing the impact on his health, safety, and personal well-being. Over the years the emphasis in monitoring worker exposures has been placed on fugitive emissions which are inhaled by workers in the normal performance of duties. The methods of controlling these exposures include 1) engineering controls - enclosures, equipment design, ventilation systems, process changes; 2) administrative controls - limiting exposure times, rotation of employees, work practices, and medical and biological evaluations;

and 3) personal protective equipment - respirators, protective clothing, eye, ear and face protectors. The major problems encountered are with multiple exposures and stresses, synergistic effects, pre-existing conditions, individual susceptibilities, and off-duty activities.

OCCUPATIONAL HEALTH STANDARDS

The concepts of a safe concentration for exposure to toxic substances originated in the late 1930's and were topics of discussion in 1938 at the first annual meeting of the American Conference of Governmental Industrial Hygienist (ACGIH). The state of Massachusetts published a list of suggested maximum concentrations for 41 substances in 1940.(1) Similar lists were set up by a number of states and values were recommended by the U.S. Public Health Service and the American National Standards Institute (ANSI). The first formal list of Threshold Limit Values (TLVs, then called maximum allowable concentrations) was published in mimeographed form in 1946 at the 8th annual meeting of ACGIH. Subsequent suggested values and lists were published in the American Industrial Hygiene Journal commencing in 1950. At present, TLVs for chemical substances are reviewed annually and published in booklet form available from ACGIH.

The TLVs established by the ACGIH for 1968 were promulgated as official Federal standards in 1969 under the Walsh-Healy Public Contracts Act.(2) These 400 TLVs constitute the mainstay of health standards applicable under the Occupational Safety and Health (OSH) Act of 1970 with the exception of twenty-two health consensus standards established by ANSI.(3) Standards for asbestos,(4) vinyl chloride,(5) coke oven emissions,(6) 14 chemical carcinogens,(7) and benzene(8) have subsequently been promulgated by the Occupational Safety and Health Administration (OSHA).

Since the OSH Act, NIOSH has developed criteria for recommended standards for over 50 chemical substances including recommended monitoring and analytical procedures. Under a joint NIOSH and OSHA effort referred to as the Standards Completion Program (SCP), the development of accurate methods for compliance monitoring and analysis for the OSHA health standards was undertaken in early 1974.(9) To date, over 200 methods have been tested and validated. These methods are presently available from the National Technical Information Service (NTIS) in sets of about 18 substances per set, costing approximately $6.00 in hardcopy. At final program completion, NIOSH plans include publication of these procedures.

MONITORING AND ANALYTICAL TECHNIQUES

Over the years, industrial hygienists have adopted personal sampling methods as the preferred approach for evaluating worker exposure to airborne contaminants. The use of miniaturized battery operated pumps which can easily be strapped to the belt of workers and sample collectors that can be clipped to the shirt lapels has become accepted practice. Generally, these pumps are operated at about 1.0 to 2.0 ℓpm for aerosols in the form of dusts, fumes and mists and 10 to 1000 mℓ per min. for gases and vapors. Flow rate through a 37 mm membrane filter used to collect particulate samples should probably not operate at less than 1.5 ℓpm so as not to sacrifice collection efficiency. However, reliable collection of gases can be effectively accomplished with solid sorbents and flow rates as low as 10 mℓ per minute.

Since the existing Federal standards are based on 8-10 hour working days, every attempt is made to collect representative samples for a working shift, usually up to 6 hour samples. Some standards also have ceiling limits which would permit evaluation based on 15 minute periods for peak exposures to contaminants. Depending on the contaminant of concern, sampling methods have been developed using midget impingers or bubblers, filter media, solid sorbent materials and in some instances sampling trains consisting of combinations of the above.

Midget impingers or bubblers are used as liquid sorbent collectors and recommended for collection of about 7 percent of the substances tested under the SCP. Impingers or bubblers using 10 to 15 mℓ of absorbing solution of liquid sorbent are attached to the lapel in an upright position in a special holder for sampling purposes. Although they are more difficult for sampling because of restricted wearer movement, possible spillage, evaporation, and breakge, they are used for sampling where other methods fail or have not been developed, such as for hydrogen sulfide, ozone, hydrogen fluoride and many organophosphate pesticides. For example, ozone is collected by aspirating a measured volume of air (45 liters recommended) through 10 mℓ of alkaline potassium iodide solution. Hydrogen sulfide is collected by drawing a measured volume of air through 10 mℓ of an alkaline suspension of cadmium hydroxide absorbing solution. In this case the impinger is wrapped in aluminum foil to prevent photodecomposition of the cadmium sulfide formed during sampling.

Filter media collectors are recommended for 10 percent of the substances tested under SCP. Several types of filter media are commonly used for collection of aerosols such as metal dust and fume, fibers and mists. The membrane filters and glass fiber filters are most common. They are routinely used for silica, lead, cadmium, beryllium, asbestos, cotton dust, sulfuric acid, arsenic and the terphenyls with success. Respirable sampling for dusts is accomplished by using a cyclone presampler to remove non-respirable dust particles. Gravimetric or chemical analysis can be performed from filter media samples. For example, sulfuric acid mist is sampled with a 37 mm, 0.8 micrometer mixed cellulose ester membrane filter supported by a cellulose backup pad in a three-piece polystyrene cassette filter holder held together with a shrinkable band or tape.

Solid sorbent media used in sampling tubes are the most popular new method in use and under continued development for a variety of substances encountered in industrial situations. Over 60 percent of the substances validated under SCP utilize solid sorbent collection media. Of these, 50 percent employ charcoal sampling tubes. Charcoal has gained universal acceptance because of its effective sorbent characteristic - essentially 100 percent for most organic solvent vapors and many gaseous substances. It has also become the most economical because of wide commercial applications. It cannot be universally utilized, however, because of the limitations of:

- adsorption with more polar compounds
- desorption, particularly with higher molecular weight compounds
- migration, particularly with some gaseous substances.

The standard (150 mg) charcoal tube is 7 cm long with an inside diameter of 4 mm and contains two sections of 20/40 mesh activated coconut charcoal. The front section contains 100 mg of charcoal while the backup section contains 50 mg of charcoal separated with a 3 mm piece of urethane foam (see Figure I). The purpose of the backup section is to determine the possibility of sample breakthrough and consequent loss. Two tubes in series are sometimes necessary to evaluate possible sample migration, e.g. butadiene. More recently, larger tubes, a 600 mg charcoal (400 mg front with 200 mg back section) and a jumbo 1000 mg (800 mg front and 200 mg back) have been developed to accommodate more volatile substances such as trifluoromonobromomethane. A wide variety of chemical types including the aliphatic and aromatic hydrocarbons, halogenated hydrocarbons, ketones, esters, and ethers can be evaluated with charcoal tube sampling techniques.

Silica gel solid sorbent collectors are recommended for use in about 7 percent of the chemical substances validated under the SCP. Silica gel is inexpensive and is an acceptable sorbent for the more polar chemical substances. The standard silica gel tube (225 mg) is 7 cm long with 4 mm inside diameter and contains two sections of 20/40 mesh silica gel. The front section contains 150 mg of silica gel while the backup section contains 75 mg of silica gel separated by a 2 mm portion of urethane foam. Silica gel sampling methods have been developed for acetylene tetrabromide, nitrobenzene, diethylamine, ethylamine, aniline, ethylmorpholine, xylidene, and dimethylamine. Larger tubes are also available and are recommended for sampling methyl alcohol. Recognized limitations with silica gel sampling tubes include a high affinity for water so that vapors may not be adequately trapped in the presence of high relative humidity.

Other types of solid sorbent collection media have been validated for only 2 percent of the substances included under the SCP. For example, the XAD-2 resin is used for ethyl silicate and nicotine sampling. Other types of solid sorbents in experimental stages are fluorosil for polychlorinated biphenyls, Porapak Q for furfural alcohol, Chromosorb 104 for mercaptans, and Tenax for the polycyclic aromatic hydrocarbons. Several different types of solid sorbent materials are being tested under laboratory conditions for reliability and applicability.(10)

Combining sampling types is sometimes required to assure adequate contaminant collection. For example, the method for sampling pentachloronaphthalene includes a glass fiber filter connected in series with a midget bubbler containing 15 mℓ of iso-octane. Nitric oxide and nitrogen dioxide may be collected on different sections of a solid sorbent tube using a triethanolamine (TEA) - impregnated molecular sieve collection media. The nitrogen dioxide is absorbed on the first section of the tube. The nitric oxide is converted to nitrogen dioxide by an oxidizer and subsequently adsorbed on the second section of the tube.

The primary analytical tool is the gas chromatograph equipped with flame ionization, electron capture, flame photometry, alkali flame ionization or electrolytic conductivity detectors. About 70 percent of the analytical methods validated under the SCP employ gas chromatographic techniques. The gas chromatograph is especially useful in testing for a wide variety of gases, vapors, and mists encountered in industrial situations. Atomic absorption used for identification and evaluation of metal dust and fume accounts for about 4 percent of the methods validated. Other analytical techniques include potentiametric, colorimetric, titrimetric, and gravimetric methods.

EXPOSURE DATA

NIOSH is responsible for monitoring and evaluating industrial exposures primarily related to mortality and morbidity studies. Present studies entail monitoring of over 40 different agents. Some current studies of interest include documentation of occupational exposure to benzene, PCBs, asbestos, epichlorohydrin, styrene and butadiene. Exposure data are reported as 8-hr. time weighted average exposures or ceiling concentrations (15 minutes) depending on the exposure situation and the appropriate standard.

A recent NIOSH mortality study of workers has shown that benzene is leukemogenic.(11) Based on this study and other available information, OSHA has promulgated an emergency temporary standard for benzene with a permissible exposure level of one part per million as an 8 hr. TWA.(8) Benzene is present in gasoline at about 2 percent by volume. Exposure levels to retail automobile service station attendants will vary depending on the liquid volume percent, air temperature, amount of gas pumped and wind direction. Ongoing NIOSH benzene monitoring studies indicate exposures to service station attendants as high as 0.8 ppm (782 ppb). Benzene exposure data are shown in Table I.

Polychlorinated biphenyls have been of concern to both EPA and NIOSH because of the potential for carcinogenic activity and the build-up of concentrations in the environment.(12) The existing Federal standard is 500 $\mu g/m^3$ for compounds containing 54% chlorine. NIOSH has monitored worker exposures to PCBs in manufacturing processes and have found levels to be about 50 $\mu g/m^3$. PCBs exposure data are shown in Table II.

The health hazards associated with exposure to asbestos fibers are well documented in the literature. The existing Federal standard is 2 fibers per cc greater than 5 microns in length as determined by optical microscopy as of July 1976.(13) NIOSH industrial hygiene studies have demonstrated the feasibility of compliance with the current standard.(14) Asbestos fiber exposures in operations where asbestos is present as contaminants of other products such as talcs are of major concern. Elevated fiber exposures have been demonstrated in these operations. A summary of asbestos exposure data obtained by optical microscopy is presented in Table III.

Certain problems are evident in the current occupational asbestos exposure monitoring process, not the least of which is the fact that only fibers larger than 5 μm in length are considered. Studies of airborne dusts in industrial asbestos exposure operations have shown that a large majority of airborne fibers (1-51%) are shorter than 5 μm with median fiber lengths ranging from <1 to 5 μm (see Table IV). A major effort is underway by NIOSH to develop and/or evaluate alternative techniques such as electron microscopy for routine monitoring.

Epichlorohydrin is well recognized to be a highly toxic chemical, a primary skin irritant and sensitizer, an upper respiratory irritant and has demonstrated both acute and chronic toxicity by every route of entry. Animal testing provides incriminating evidence as to possible mutagenic, teratogenic and carcinogenic effects. The existing Federal standard is 5 ppm with a NIOSH proposal to reduce the level to 0.5 ppm.(15) Monitoring levels in manufacturing facilities indicate the levels generally to be within the existing and proposed limits. Table V shows a summary of exposure data for several epichlorohydrin manufacturing operations.

NIOSH is currently conducting an environmental-epidemiological study of the styrene-butadiene rubber idnsutry. This study was prompted by industry reporting 8 cases of leukemia at their Port Neches, Texas facilities in March, 1976. McMichael et al have reported that workers employed in a facility where synthetic rubber was manufactured had a six-fold relative risk of dying from lymphatic and hemopoietic malignancies as compared to other workers in the same tire manufacturing plant who had not worked in the synthetic rubber production.(16) The current Federal standard for styrene is 100 ppm and for 1,3 butadiene is 1000 ppm. Monitoring revealed very low exposure levels, well within the standards and generally less than 5 ppm. A summary of exposure data for styrene and butadiene is shown in Table VI.

SUMMARY AND CONCLUSIONS

Fugitive emissions from industrial sources are a mutual concern to NIOSH in evaluating worker exposure and to EPA in evaluating the environmental effects. However, the approach to evaluation is often different because the purposes for monitoring and monitoring locations are usually different. Personal sampling does not usually reflect short-term exposure to high concentrations,but rather averages of the exposure over a full shift. Workers who must perform a job in areas of possible high exposure concentrations such as maintenance workers under extreme exposure conditions, must be provided with control devices or must limit exposure times to meet existing standards.

Environmental sampling has traditionally been based on high volume sampling techniques. With the development of more sophisticated analytical technologies, in some instances, environmental monitoring to detect fugitive emissions may be accomplished by employing some of the more recently developed miniaturized sampling techniques.

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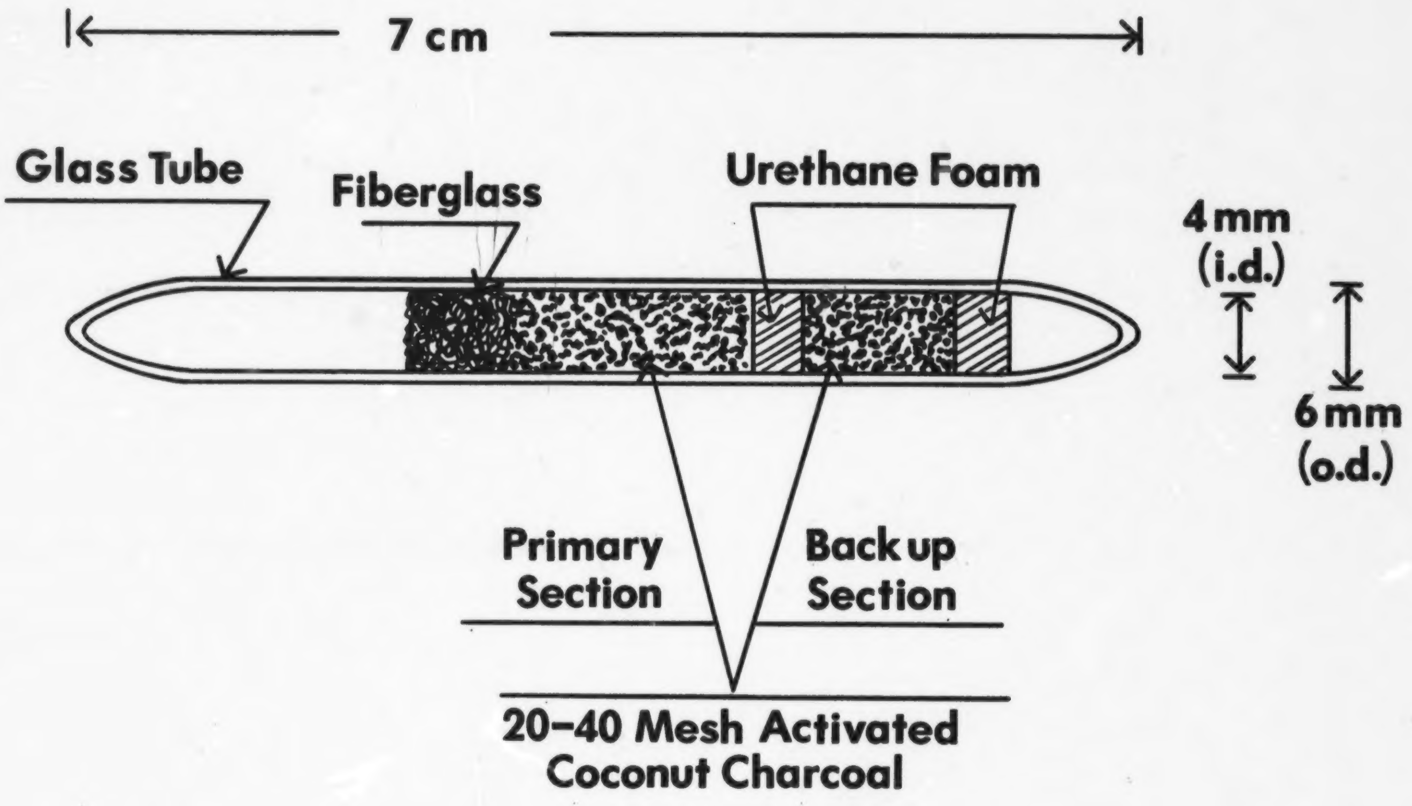
7 cm
Glass Tube
Fiberglass
Urethane Foam
4 mm (i.d.)
6 mm (o.d.)
Primary Section
Back up Section
20–40 Mesh Activated Coconut Charcoal

FIGURE 1. CHARCOAL SAMPLING TUBE

TABLE I
SERVICE STATION ATTENDANTS' EXPOSURE TO BENZENE

TEMP., °F	WIND SPEED MPH	NOZZLE TIME, SEC.	FUEL PUMPED, GAL.	2 HR. EXPOSURE, PPB
-24	--	1221	173.7	14
59	2.1	206	144.6	158
49	3.6	902	158.6	782
42	1.2	1016	225.9	205
71	3.7	52	58.3	35

SOURCE: HARTLE, R., UNPUBLISHED DATA

TABLE II

PCB'S - SUMMARY PLANT DATA

EMPLOYEE'S 8 HOUR TWA EXPOSURE TO PCB AT MANUFACTURING FACILITIES, JULY, 1976

OCCUPATIONAL TITLE	8 HR. TWA (μG/M^3)
CHLORINATOR OPERATOR	33
TANK FARM AND SHIPMENT	44
DISTILLATION COLUMN OPER.	57
STILL OPERATOR	63
INCINERATOR OPERATOR	45

SOURCE: JONES, M., UNPUBLISHED DATA.

TABLE III

SUMMARY OF OVER 10,000 SAMPLES ANALYZED FOR ASBESTOS FIBER LEVELS BY INDUSTRIAL CATEGORY. CONCENTRATIONS DETERMINED BY OPTICAL MICROSCOPY

INDUSTRY	RANGE OF MEANS (FIBRES > 5 µM/ML)	RANGE OF INDIVIDUAL SAMPLES (FIBRES > 5 µM/ML)
TEXTILE	0.1 - 29.9	0.0 - 143.9
INSULATION	0.1 - 74.4	0.0 - 208.4
PAPER PACKING AND ASPHALT PRODUCTION	0.2 - 13.6	0.0 - 18.9
CEMENT SHINGLES, MILLBOARD AND GASKET	0.1 - 4.4	0.0 - 16.6
FRICTION	0.1 - 14.4	0.1 - 32.4
CEMENT PIPE	0.2 - 6.3	0.0 - 13.4
TALC PRODUCTION	2.1 - 7.0	0.3 - 29.1*
GARAGES	0.1 - 0.2	0.0 - 15.3*

SOURCE: DEMENT, J. ET AL, AN. N.Y. AC. OF SC., VOL. 271, P. 345-352, 1976

* DEMENT, J., (UNPUBLISHED DATA)

TABLE IV

SUMMARY OF TYPICAL AIRBORNE FIBER LENGTHS FOR TYPICAL INDUSTRIAL OPERATIONS AS DETERMINED BY ELECTRON MICROSCOPY

OPERATION	% > 5 µM
TEXTILE	
FIBRE PREPARATION & CARDING	4
SPINNING, TWISTING, WEAVING	2
FRICTION	2
ASBESTOS-CEMENT PIPE	
MIXING	2
FINISHING	1
PIPE INSULATION	51
HARDROCK MINING	7*
TALC PRODUCTION	3*

SOURCE: DEMENT, J. ET AL, AN. N.Y. AC. OF SC., VOL. 271
P. 345-352, 1976

*DEMENT, J. (UNPUBLISHED DATA)

TABLE V

EPICHLOROHYDRIN-SUMMARY PLANT DATA

EMPLOYEE'S 8 HOUR TWA EXPOSURE TO EPICHLOROHYDRIN AT MANUFACTURING FACILITIES, 1976

OCCUPATIONAL TITLE	8 HR TWA (PPM)
GLYCERIN CONTROL OPER.	0.4
GLYCERIN SHIFT FORMAN	0.2
TANK CAR LOADING	0.3
EPOXY RESIN OPERATOR	0.1

SOURCE: OSER, J., UNPUBLISHED DATA

TABLE VI

SBR - SUMMARY PLANT DATA

EMPLOYEE'S 8 HOUR TWA EXPOSURE TO STYRENE AND BUTADIENE AT A SBR FACILITY, JULY 1976

OCCUPATIONAL TITLE	8 HR. TWA (PPM)	
	STYRENE	BUTADIENE
REACTOR OPERATOR	0.3	1.8
TANK FARM OPERATOR	0.7	1.9
REACTOR OPERATOR	1.3	0.8
COAGULATION OPERATOR	1.0	0.1
BLEND OPERATOR	1.1	0.03

SOURCE: YOUNG, R. ET AL, UNPUBLISHED DATA

Tuesday Morning - May 24, 1977

SESSION III: CONTROL

Chairman: Henry J. Kolnsberg, *TRC*

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MODELING FUGITIVE PARTICULATES FOR CONTROL STRATEGY DEVELOPMENT - A CASE HISTORY

By

George A. Jutze

and

John M. Zoller

PEDCo Environmental, Inc.

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MODELING FUGITIVE PARTICULATES FOR CONTROL STRATEGY DEVELOPMENT - A CASE HISTORY

George A. Jutze
PEDCo Environmental, Inc.

John M. Zoller
PEDCo Environmental, Inc.

ABSTRACT

This presentation discusses the various data gathering efforts and modeling requirements which were utilized to evaluate a series of particulate control strategies applicable to the Clark-Mohave-Yuma (Las Vegas) Air Quality Control Region. Since relatively few uncontrolled point sources and conventional area sources of total suspended particulates (TSP) exist in this region, fugitive particulates/dust sources were identified as producing an impact on air quality which affects non-attainment of the NAAQS for TSP. The results of control strategy testing utilizing the Hanna-Gifford simulation are presented.

BACKGROUND

At the present time the National Ambient Air Quality Standard (NAAQS) for Total Suspended Particulate (TSP) is being exceeded in the Clark-Mohave-Yuma (Las Vegas) and Northwest Nevada Intrastate (Reno) Air Quality Control Regions (AQCR). Since relatively few uncontrolled point sources and conventional area sources of TSP have been identified in these regions, the probability existed that the impact on TSP air quality from fugitive dust sources is causing non-attainment. PEDCo Environmental was contracted by the U.S. Environmental Protection Agency, Region IX, to assist the state and local agencies in evaluating this matter.

PURPOSE AND SCOPE

The purpose of this project was to:

(1) identify the sources impacting or projected to impact in the future on sampling sites and other receptor locations with high particulate concentrations;

(2) determine the relative contribution of each of the identified sources and source categories;

(3) recommend control strategies; and

(4) estimate the expected effectiveness of the recommended control strategies on emission reductions and on ambient air quality.

To accomplish these goals, six specific tasks were performed as described below:

A. Air Quality Monitoring Data

All necessary air quality and meteorological data in the study areas for the base year 1975 were assembled and analyzed to better identify the nature of the particulate problem. "Micro-inventories" of the areas surrounding each hi-vol location were also conducted to determine specific sources and source categories influencing the measurements at the sites.

B. Factors Influencing Emissions from Fugitive Sources

All fugitive dust and naturally occurring dust source categories were identified and available emission factors and data relative to variations in and particle size distribution of the emission rates were assembled. From these data, estimates of emission rates by particle size range for each fugitive dust source category were derived. Functions were developed to describe variations in these expected emission rates.

C. Emission Inventory and Emission Projections

An emission inventory of all point and area sources of particulate, including fugitive dust and background sources, was prepared for each study area. Emissions were accurately allocated into a grid system. The emission estimate subtotals in each category were provided by season and particle size range. Projected emission inventories for 1980 and 1985 were prepared in the same format as the base-year inventory.

D. Emission Modeling

A relationship between emissions and ambient air quality was derived for the study areas. The model was then used to calculate concentrations at each of the specified receptor sites for the base year and 1985.

E. Control Strategy Development

Potential control measures for significant source categories were reviewed. As a result, five control strategies were independently evaluated in the Las Vegas area and three strategies in the Reno area. The recommended strategies were tested by input of the estimated reduced emissions to the source-receptor model developed in Task D.

F. Particulate Characterization

An analysis of hi-vol glass fiber, hi-vol cellulose acetate, and Andersen glass fiber were compared with inventory results for each sampling site for determination of source contribution. The filters analyzed were both historical (hi-vol glass fiber) and the results of a four-week special sampling program (hi-vol glass fiber, cellulose acetate, and Andersen glass fiber). In addition, approximately fifteen particulate grab samples of soil, deposited dust, and the like were analyzed from each of the project study areas. Analysis included microscopic, silica fraction, combustible fraction, and two suspect metals (calcium and lead).

A project report was prepared for each task and are entitled as follows:

- Task A Report - Air Quality Monitoring Data
- Task B Report - Factors Influencing Emissions from Fugitive Sources
- Task C Report - Emission Inventory and Emission Projections
- Task D/E Report - Emission Modeling and Control Strategy Development (Las Vegas)
- Task D/E Report - Emission Modeling and Control Strategy Development (Reno)
- Task F Report - Particulate Characterization Study

At certain points in this presentation, the various "Task Reports" will be cited. However, the material discussed herein basically deals with the Task D/E Reports for Las Vegas and Reno.

MODEL DESCRIPTION

To evaluate the impact of control strategies, it is necessary first to develop a relationship between emissions and air quality. Several diffusion modeling techniques have been suggested by the U.S. Environmental Protection Agency for this purpose, including: Miller-Holzworth, AQDM, and Hanna-Gifford. The Hanna-Gifford approach was evaluated for applicability based on several reasons. The emission density vs. air quality relationship developed in the Task A Report showed a reasonable correlation, but not high enough to be used to estimate air quality. The Hanna-Gifford simulation is a more sophisticated approach to emission density and air quality relationships and is expected to give a better correlation. Few major (tall stack) point sources are present in the study area. These sources would be evaluated poorly by Hanna-Gifford. This model best accomodates sources with low-level emission heights. This is typical of the source categories in the study area. Fugitive dust sources are generally ground level.

The basic model is an expression developed by S.R. Hanna and F.A. Gifford to calculate the impact of various sources on a central receptor over a long period of time. The expression, the result of integrating the receptor-oriented Gaussian plume equation over upwind area sources (grids), is:

$$\chi = \sqrt{\frac{2}{\pi}}\,\frac{1}{u}\,\frac{(\Delta x/2)^{1-b}}{a(1-b)}\left\{Q_o + \sum_{i=1}^{n} Q_i\,[(2i+1)^{1-b} - (2i-1)^{1-b}]\right\}$$

where

χ = concentration in a grid, $\mu g/m^3$

u = wind speed, m/sec

Δx = grid width, m

a,b = stability coefficients (a = 0.15, b = 0.75 for urban areas)

Q_o = source strength of receptor grid, $\mu g/m^2$-sec

Q_i = source strength of i^{th} grid away from the receptor grid, $\mu g/m^2$-sec

n = number of grids in any one direction which will have a significant impact on the receptor grid, for this study assume n = 2.

For an area marked off in grids of a given size, the quantity

$$\sqrt{\frac{2}{\pi}} \; \frac{(\Delta x/2)^{1-b}}{a(1-b)} = \text{constant} = C$$

For a 2 km grid, Δx = 2000 m and C = 119.6.

For a 5 km grid, Δx = 5000 m and C = 150.5.

For a 6 km grid, Δx = 6000 m and C = 157.5.

It was assumed that the air quality of each receptor grid is affected not only by the emissions of that grid but also by the emissions from two rings of surrounding source grids. The quantity within the square brackets [ ] in the first equation expresses the relative contribution of these emissions based on distance in terms of number of grids (i) away from the receptor. This scheme has been modified for this study by assuming that the impact of the source grid emissions on a receptor grid is proportional to the distance between the centers of these grids in relative grid widths.

In the original model, for each grid in the ring of grids nearest the receptor the relative impact of the emissions is the same, since for each of these grids i = 1. In the modified version i = 1.00 for grids which have a side in common with the receptor grid. However, for grids which lie on the diagonal of the central grid, i = 1.41. Consequently, emissions from these grids have a lesser impact than those from grids having a common side with the receptor.

Note, the grid sizes cannot be mixed. Impact on a receptor must be calculated from source grids of an equivalent size. Therefore, in order to estimate air quality in those 2 km grids which are nearest the 5 km grids (in Las Vegas) or 6 km grids (in Reno), it was necessary to create two rows of artificial 2 km grids whose emissions were fractional parts of the emissions of the corresponding larger km grids. Two rows of artificial 5 or 6 km grids must, likewise, be created around the entire grid network. Since an emission inventory for these areas does not exist, the emissions of the perimeter grids were repeated. This appears to be a valid assumption in light of the fact that the two areas, gridded and non-gridded, have a similar make-up, and that if these areas were assumed to have zero emissions the air quality impact might be severly underestimated. Also, within the central part of the grid system, artificial 5 or 6 km grids were composed of combinations of 2 km grids.

Meteorological conditions will also have an effect on air quality. The impact of the emissions from each source grid was weighted based on the frequency of occurrence of the wind out of the direction that grid lies from the receptor. Wind speed was also varied with wind direction. Historical data and a sixteen-point compass were used.

The emission inventory data were used as input to the model. Measured annual geometric mean concentrations were correlated against the modeled air quality at each of the ten sampling stations in Las Vegas and nine sampling stations in Reno. Very few sampling stations were located at the center of a grid. Therefore, the modeled air quality was obtained by weighting the modeled impact from each grid which at least partially occupies an imaginary grid of equal size having a sampling site at its center. The grids at each sampling site, their allocation factors, and the results of this correlation procedure are shown in Tables 1 and 2. Correlation results (0.69 for Las Vegas and 0.79 for Reno) show that the Hanna-Gifford approach is an acceptable diffusion model to use in this study. Statistical analyses support the assumption that this correlation does indeed show that there is a significant relationship between measured and modeled air quality using the Hanna-Gifford model. The slope and intercept are the parameters required to calibrate the model for comparison to actual data.

The intercept of the correlation is normally assumed to be an indication of background concentration which is unaccounted for by any known source of emissions within a given area. Although the intercept of the correlation is provided by the best fit of a line through measured versus modeled data, the value 51.3 shown in Table 1 is not representative of background levels in Las Vegas. The Clark County District Health Department suggested using a background value of 35 $\mu g/m^3$ based on three year running averages from their background station. Due to the large intercept obtained from the correlation, several other methods were investigated in an attempt to develop an improved relationship between measured and modeled data. Separate correlations for high and low concentrations, and for urban and rural concentrations, however, provided no better relationship. The average difference between measured and modeled data, which may also be used as an indi-

Table 1. CORRELATION OF LAS VEGAS ANNUAL GEOMETRIC MEANS WITH MODELED AIR QUALITY

Site	Grids	Uncalibrated model impact μg/m³	Allocation factors	Grid contribution μg/m³	Modeled air quality at site μg/m³	Measured annual geometric mean[a] μg/m³
A, Las Vegas Airport	33	6.8	1/2	3		
	43	43.8	1/2	22	25	69
B, Basic School	15	9.6	2/3	6		
	29	20.7	1/3	7	13	64
C, Clark Co. Health Dept.	91	47.3	5/8	29		
	101	33.5	3/8	13	42	91
D, Henderson Post Office	28	14.4	1/4	4		
	29	20.7	1/4	5		
	40	87.0	1/2	43	52	92
E, Las Vegas Fire Dept. 1	92	70.0	1/4	17		
	102	43.6	3/4	33	50	82
F, Las Vegas Fire Dept. 2	93	42.3	1/2	21		
	94	27.0	1/2	14	35	105
G, Nellis Air Force Base	138	8.4	1/1	8	8	51
H, North Las Vegas	117	32.0	1/1	32	32	105
I, Sahara Hotel	79	39.7	1/2	20		
	80	43.0	1/2	21	41	117
J, Las Vegas Stadium	50	25.4	1/1	25	25	64
K, Sunrise Power Plant[b]	73	33.0	1/8	4		
	85	168.8	7/8	148	152	92
L, Las Vegas Wash.[c]	-	-	-	-	-	32
Correlation					0.689	
Slope					1.012	
Intercept					51.320	

[a] Calculated using October 1974 through September 1975 data.

[b] Site K was not included in the correlation because of an apparent sampling site bias.

[c] Site L was not included in the correlation because it is located outside of the gridded study area.

Table 2. CORRELATION OF RENO ANNUAL GEOMETRIC MEANS WITH MODELED AIR QUALITY

Site	Grids	Uncalibrated model impact µg/m^3	Allocation factors	Grid contribution µg/m^3	Modeled air quality at site µg/m^3	Measured annual geometric mean[b] µg/m^3
A, Washoe County Health Dept.	41	81.4	7/9	63		
	42	115.0	2/9	26	89	77
B, Cal-Neva Club	40	50.6	1/3	17		
	41	81.4	2/3	54	71	74
C, Jessie Beck School	26	18.1	2/9	4		
	32	35.3	6/9	23		
	33	62.3	1/9	7	34	44
D, Reno Airport	28	26.1	2/9	6		
	34	40.1	6/9	27		
	35	19.6	1/9	2	35	65
E, Nevada Fish and Game	41	81.4	1/3	27		
	48	51.8	2/3	35	62	57
F, Mamie Towles School	39	32.9	1/2	17		
	46	40.5	1/2	20	37	32
G, Greenbrae School	51	39.0	1/1	39	39	58
H, Sparks Nugget[a]	43	39.1	5/9	21		
	44	61.3	1/9	7		
	50	38.6	3/9	13	41	90
J, Verdi School	16	10.5	1/2	5		
	37	13.1	1/2	7	12	18
L, Sewer Plant	24	19.2	1/2	10		
	45	22.6	1/2	11	21	50
Correlation						0.793
Slope						0.617
Intercept						25.360

[a] Site H was not included in the correlation because of an apparent sampling site bias.

[b] Calculated using October 1974 thru September 1975 data.

cation of background, also failed to improve the relationship. This value of 51.7 $\mu g/m^3$ did not favorably agree with background levels measured by the local agency. An attempt to force-fit a line through the suggested background value of 35 $\mu g/m^3$ would result in a calibration which would overpredict the large concentrations and underpredict the low ones.

Based on the investigation described above, it was decided to use the slope of the original correlation, shown in Table 1, and the background value (intercept) of 35 $\mu g/m^3$ suggested by the Clark County District Health Department. All subsequent model runs predict air quality concentrations according to the following expression:

predicted air quality = (1.012)(modeled air quality) + 35.

This equation produces predicted concentrations which are on the order of 16 $\mu g/m^3$ lower than those which would result if the correlation intercept were used.

The slope and intercept were the parameters used to calibrate the model in Reno for comparison to actual data (Table 2). Subsequent model runs predict air quality concentrations according to the following expression:

predicted air quality = (0.617) (modeled air quality) + 25.4

The value 25.4 may also be looked upon as a background concentration which is unaccounted for by any other source of emissions. This value is considered to be an acceptable background value by the Washoe County District Health Department. It is also in good agreement with the intercept from the emission density versus air quality correlation presented in the Task A report.

CONTROL STRATEGIES

Several control possibilities were discussed with Clark County District Health Department, Air Pollution Control Division personnel. These strategies were designed to affect the major source categories in the study area. Initially, the following strategies were considered:

Street cleaning,
Stationary source control,
Stabilization of railroad yards,
Control of construction emissions,
Reduction of emissions from cleared areas, and
Reduction of unpaved road emissions.

All of these strategies, except control of construction emissions, were then evaluated using the Hanna-Gifford relationship. The current regulations on construction are considered by the agency as adequate; their limiting factor being enforceability. The others were evaluated by first determining the emission reduction efficiencies that are expected for each strategy. A weighing factor was then applied to better estimate the actual impact on air quality that each strategy will have. (This is explained in the following section.) The resulting emissions were then input to the Hanna-Gifford model to predict the resultant air quality.

As in Las Vegas, several control possibilities were discussed with Washoe County District Health Department, Air Pollution Control Division personnel. These strategies were designed to affect the major source categories in the study area. Initially, the following strategies were considered.

Street cleaning,
Stationary source control,
Control of construction emissions,
Reduction of unpaved road emissions, and
Reduction in emissions from controlled burning.

In discussions with the local agency, two of these strategies, stationary source control and reduction in emissions from controlled burning, were eliminated from further consideration. This was because the stationary source of principal concern would not be operating by 1985 and reduction in emissions from controlled burning is not considered feasible. The other strategies were evaluated by first determining the emission reduction efficiencies that are expected for each strategy. A weighing factor was then applied to better estimate the actual impact on air quality that each strategy will have. The resulting emissions were then input to the Hanna-Gifford model to predict the resultant air quality.

DEVELOPMENT OF A WEIGHING FACTOR

In attempt to estimate more closely the impact on air quality that will be expected from emission reductions, development of a weighing factor was investigated in the Task F Report, Particulate Characterization Study. This factor was developed because of the large disparity between the percent mineral observed on hi-volume sampler filters and the percent mineral emissions in the microinventories surrounding the hi-vol sites. A much higher percent of the emissions were mineral than were collected on the filters. Therefore, a reduction in mineral emissions can not be expected to result in an equal reduction in filter loading.

From the microinventory of selected sites in Las Vegas and Reno, all emissions were identified and classified as being from mineral, tire wear, or combustion sources. Also, high volume samples (millipore and glass fiber), which were taken at these sites, were analyzed under Task F for the percent by weight of material from the same source classifications. The mineral percentage by weight of both the emissions and the filter loadings are shown in Table 3.

It has been observed that a high percentage of all microinventory emissions at the selected sites are from mineral sources. One would expect a similar percentage of minerals to appear on the sample filters. This, however, was not the case. On the average, the sample filters showed a percentage of mineral impact which was only 60 percent of the percentage of mineral emissions. Therefore, reductions in mineral emissions and reductions in ambient air quality are not expected to occur in a one-to-one ratio.

Since the control strategies are applied to mineral emissions, only 60 percent of any reduction in emissions due to the control strategies will be observed in the ambient air quality as measured by the high-volume sampler. Therefore the weighing factor will be applied as follows:

Control strategy reduction, percent
times
Weighing factor, 0.60
equals
Effective percent reduction

The effective percent reduction is then applied to each applicable emission category to generate the emissions that are input to the Hanna-Gifford model for strategy evaluation. This is as follows:

Affected category emissions (by grid)
times
effective percent reduction
equals
reduction in category emissions (by grid)

Table 3. FUGITIVE DUST WEIGHING FACTOR

Site	Microinventory emissions, percent mineral	Glass fiber filters, percent mineral	Reduction ratio, Glass fiber / Microinventory	Millipore filters,[a] percent mineral	Reduction ratio,[a] Millipore / Microinventory
Henderson P.O.	96	70	0.73	61	0.64
Sahara	92	51	0.55	42	0.46
Sunrise	99	75	0.76	70	0.71
Average			0.68		0.60

Overall Average Reduction Ratio 0.64[b]

[a] Ratio of percent mineralcollected on the hi-vol filter divided by the percent mineral emissions in the microinventory at the hi-vol site.

[b] For this study, the reduction ratio (weighing factor) was rounded to 0.60, as agreed to by the Clark County District Health Department.

Site	Microinventory emissions, percent mineral	Glass fiber filters, percent mineral	Reduction ratio,[a] Glass fiber / Microinventory	Millipore filters, percent mineral	Reduction ratio,[a] Millipore / Microinventory
Cal-Neva Club	61	38	0.63	33	0.55
Sparks-Nugget	65	43	0.67	32	0.50
Washoo Health Dept.	77	41	0.53	51	0.66
Average			0.61		0.57

Overall Average Reduction Ratio 0.59[b]

[a] Ratio of percent mineral collected on the hi-vol filter divided by the percent mineral emissions in the microinventory at the hi-vol site.

[b] For this study, the reduction ratio (weighing factor) was rounded to 0.60, as agreed to by the Washoe County District Health Department.

Total category emissions (by grid)
minus
reduction in category emissions (by grid)
equals
emissions input to control strategy evaluation.

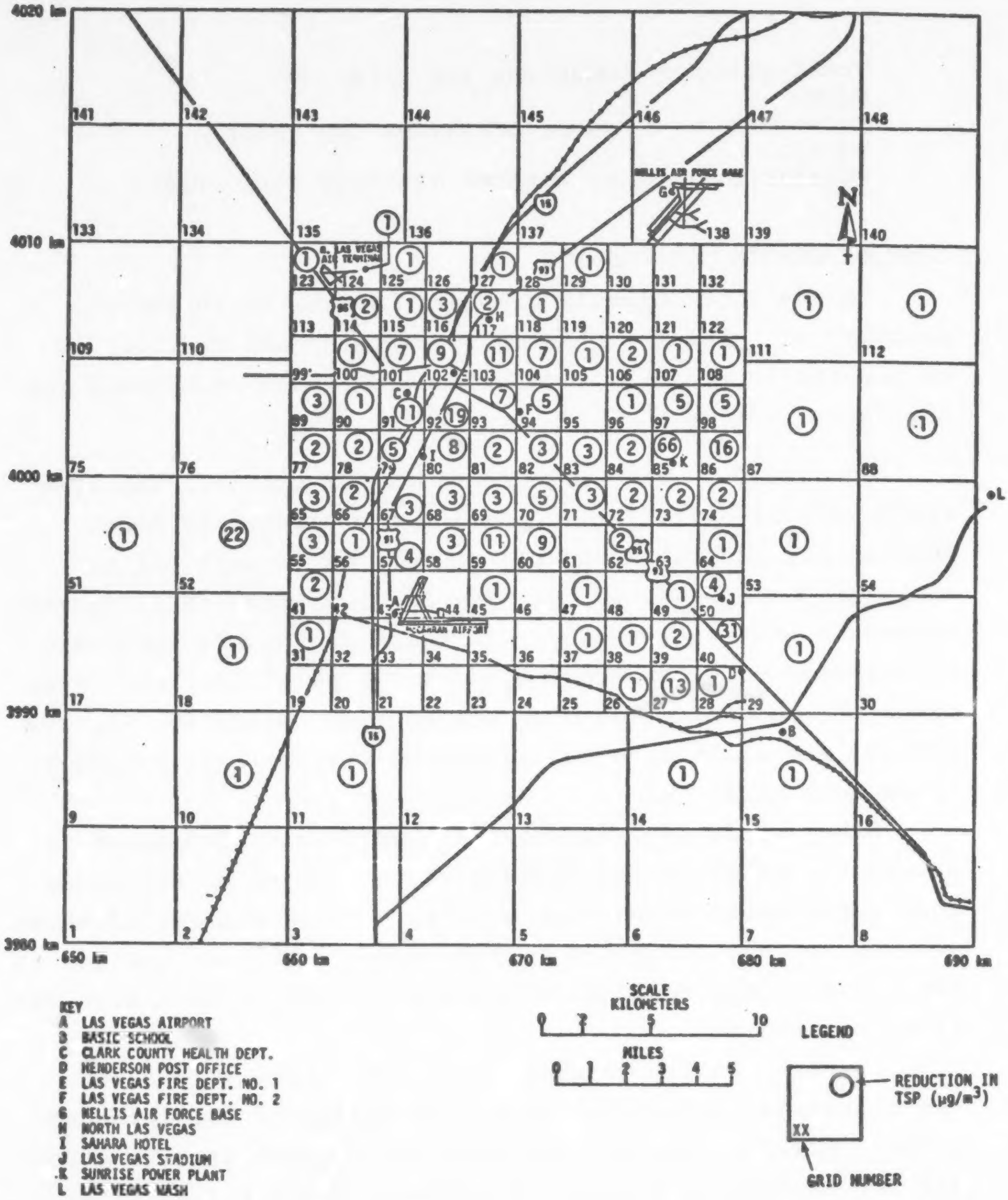
CONTROL STRATEGIES RESULTS

Figure 1 graphically displays reductions in TSP annualized air quality achieved by applying all control strategies to the 1985 uncontrolled emissions estimated for Las Vegas.

According to the projected 1985 air quality, the area which will have difficulty meeting the primary National Ambient Air Quality Standards (NAAQS) of 75 $\mu g/m^3$ is an eight grid area (79, 80, 91, 92, 93, 101, 102, 103), concentrated in the central city. In these grids, the NAAQS are anticipated to be exceeded by up to 40 $\mu g/m^3$ in 1985. Even after the control strategies are applied, grids 92, 93, 102 and 103 are still expected to exceed the national standards by as much as 20 $\mu g/m^3$.

Other grids (40, 52, 85, 86), which are also shown to exceed the NAAQS, do so because of the impact of emissions from large local industrial sources. While control of these sources are not projected to reduce the local air quality to the level of the national standards, it will make a significant improvement.

The air quality in grid 62 is also shown to exceed the standards, primarily due to the emissions from cleared areas. However, the control strategy of soil stabilization did not include this area. Therefore, the air quality in this locality is expected to remain above the standards.



4020 km
4010 km
4000 km
3990 km
3980 km
650 km
660 km
670 km
680 km
690 km
NELLIS AIR FORCE BASE
N. LAS VEGAS AIR TERMINAL
McCARRAN AIRPORT
N
KEY
A LAS VEGAS AIRPORT
B BASIC SCHOOL
C CLARK COUNTY HEALTH DEPT.
D HENDERSON POST OFFICE
E LAS VEGAS FIRE DEPT. NO. 1
F LAS VEGAS FIRE DEPT. NO. 2
G NELLIS AIR FORCE BASE
H NORTH LAS VEGAS
I SAHARA HOTEL
J LAS VEGAS STADIUM
K SUNRISE POWER PLANT
L LAS VEGAS WASH
SCALE
KILOMETERS
0 2 5 10
MILES
0 1 2 3 4 5
LEGEND
REDUCTION IN TSP (μg/m³)
XX
GRID NUMBER

Figure 1. Total change in 1985 Las Vegas air quality due to all control strategies.

The same situation applies to grid 43 since the control strategy affecting emissions from unpaved roads, which is the main source in this grid, does not include this area.

Finally, the area in and around grid 48 is also shown by the model to slightly exceed the NAAQS. However, the major source of emissions in this grid is a power plant. Since the Hanna-Gifford model tends to over-predict sources such as this (emissions from a relatively tall stack) actual air quality in this grid is not expected to exceed the national standard in 1985.

Figure 2 shows, for Reno, the projected 1985 TSP annualized air quality resulting from the application of all control strategies.

According to the projections, only grid 41 in Reno in 1985 will be exceeding the primary National Ambient Air Quality Standards (NAAQS) of 75 $\mu g/m^3$. The source category of normal paved streets accounts for 59 percent of the emissions in grid 41. It is anticipated that the air quality standards can be met in this grid with the application of the proposed control strategy of street cleaning. This will lower the air quality from an estimated 78 $\mu g/m^3$ to approximately 73 $\mu g/m^3$.

The other strategies reduce the projected emissions, but only in grids that are already anticipated to be meeting the primary NAAQS. Therefore, the only strategy that need be considered for implementation is street cleaning.

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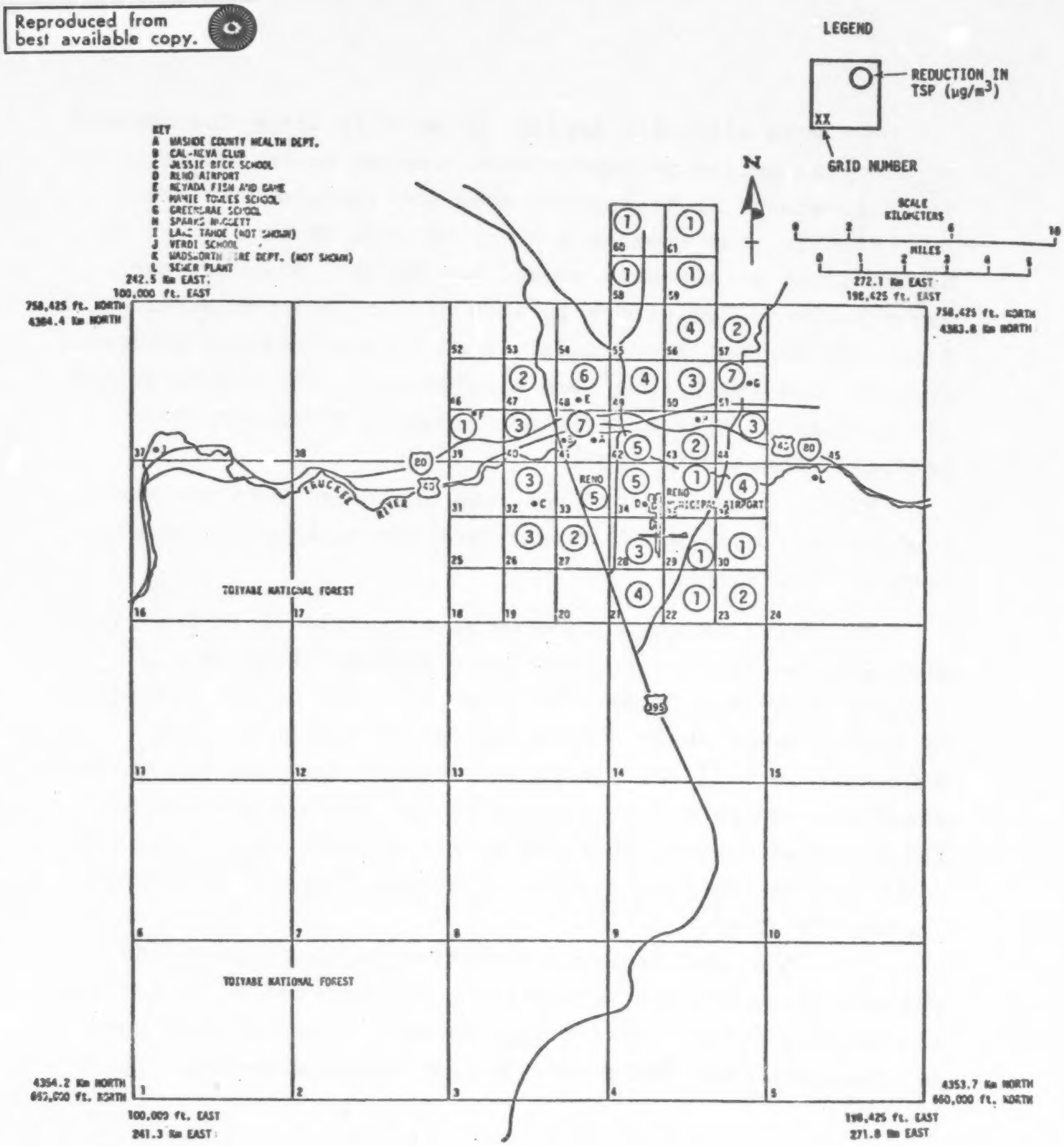
LEGEND
REDUCTION IN TSP (μg/m³)
XX
GRID NUMBER
N
SCALE KILOMETERS
0 2 6 10
MILES
0 1 2 3 4 5
KEY
A WASHOE COUNTY HEALTH DEPT.
B CAL-NEVA CLUB
C JESSIE BECK SCHOOL
D RENO AIRPORT
E NEVADA FISH AND GAME
F MAMIE TOWLES SCHOOL
G GREENBRAE SCHOOL
H SPARKS McGEE
I LAKE TAHOE (NOT SHOWN)
J VERDI SCHOOL
K WADSWORTH FIRE DEPT. (NOT SHOWN)
L SEWER PLANT
242.5 Km EAST.
100,000 ft. EAST
758,425 ft. NORTH
4384.4 Km NORTH
272.1 Km EAST
198,425 ft. EAST
758,425 ft. NORTH
4383.8 Km NORTH
TRUCKEE RIVER
RENO
RENO MUNICIPAL AIRPORT
TOIYABE NATIONAL FOREST
TOIYABE NATIONAL FOREST
80
40
395
4354.2 Km NORTH
662,000 ft. NORTH
100,000 ft. EAST
241.3 Km EAST
4353.7 Km NORTH
660,000 ft. NORTH
198,425 ft. EAST
271.8 Km EAST

Figure 2. Total change in 1985 Reno air quality due to all control strategies.

ASBESTOS WASTE EMISSION CONTROL

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ASBESTOS WASTE EMISSION CONTROL

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ABSTRACT

Asbestos products manufacturing waste dumps can be a significant source of asbestos emissions and consequently a health threat. A strategy is revealed which evaluates control concepts applicable to a model typical plant. As a result of the evaluation, a curve can be drawn which gives the least-cost control methodology to be applied to achieve a given level of emission control. Field tests designed to demonstrate the effectiveness of the selected control systems are described. Practical considerations on the field testing of emission control systems are discussed.

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INTRODUCTION

Adverse health effects associated with asbestos have caused it to be listed as a hazardous substance by the Federal EPA. Asbestos present in the ambient air may pose a health threat to the general population who are not occupationally exposed to asbestos. One source of asbestos in the ambient air is the waste dumps located throughout the United States where asbestos waste has been allowed to accumulate over the years.

This paper reveals the strategy used in a study to investigate those methods which might be employed to reduce the fugitive emissions from asbestos waste dumps. Although the study was directed specifically towards asbestos waste dumps, the strategy used to approach the problem can be used in other industries where the waste can give rise to fugitive emission problems.

In general terms the strategy was to divide the problem into several tasks as:

- Identify sources of emissions
- Cost effectiveness evaluation of control options
- Field test the most promising control options
- Provide conclusions and recommendations.

This paper discusses the emissions problem of asbestos waste from the fabrication of asbestos cement pipes.

FUGITIVE EMISSION SOURCES

The asbestos industry is not a small industry. World consumption currently stands at about 5 million tons per year. Approximately 1 million tons are used annually in the United States. Asbestos cement products account for 70 percent of the total United States usage. Products made from asbestos cement include pipe, wall siding, roof shingles, wallboard, and insulation products. It is estimated that 5-10 percent of the product material is dumped as scrap, of which 10 percent is fine dust and 90 percent coarse scrap from trimmings and breakage and from products which have failed quality assurance testing.

The quantity of waste material from the asbestos cement industry may be readily estimated. Of the 560,000 tons of asbestos used in asbestos cement products annually, 7.5 percent is scrapped. Since asbestos products contain an average only 25 percent asbestos, then the total quantity of asbestos cement products disposed of as scrap per annum is about 168,000 tons.

Over the years the scrap products have grown into substantial waste piles. Dumping of the scrap is usually carried out with little or no attempt to control the fugitive emissions associated with the various stages of the waste transfer and dumping operations.

Fugitive emissions will result from four basic processes:

- Dumping of fines, reject pipe, and aggregates

- Crushing and smoothing of the reject pipe on the active pile
- Weathering of the active pile
- Weathering of the inactive pile

In a typical plant fines collected at several baghouse locations are periodically emptied over the course of a day. The fines are taken by truck and emptied onto the waste dump. Reject pipe along with other large waste aggregates are also collected several times a day and taken to the dump to form a separate pile.

On a monthly basis, waste pipe is broken into fragments by the action of a bulldozer (which weighs about 25 metric tons) passing over the pipe. In this manner, a bed of fragments is created. Fine waste material is then spread over the pipe fragments to fill the voids and to form a relatively level surface.

The active pile is that portion of the dump where fresh waste material is added and is periodically crushed and leveled. The active pile is the dump in use. It is subjected to vehicular traffic and on an area basis results in a high emission factor.

An inactive pile is that portion of the dump to which new wastes are no longer added and is not subject to any disturbance. The emission rate is a function of the size and age of the inactive pile.

COST EFFECTIVENESS EVALUATION OF CONTROL STRATEGIES

Environmental engineering estimates were made to assess the relative magnitude of the emissions from the primary sources identified above. The results indicate that while crushing and leveling has a very high emission rate, the short time duration of the operation reduces its relative emission rate to only 6 percent of the total. Estimates of the four sources are shown diagramatically in Figure 1. Field measurements taken subsequent to the estimation showed the values to be reasonable and realistic.

Emission control technologies have been developed in other industries for the control of fugitive emissions and the stabilization of waste dumps. Some of the more feasible control methods were studied for application with asbestos waste. They are listed in Table 1.

Table 1

WASTE EMISSION CONTROL OPTIONS

Source	Duration	Control Option
Waste dumping	While active	Slurry, bag, agglomerate and crush in-plant, spray-during dumping.
Crushing and leveling	While active	Crush in-plant, spray and chemical treatment-during operation.
Active pile	<1 year	Chemical stabilization, spray, foam, and landfilling - monthly.
Inactive pile	>1 year	Physical cover, vegetative cover-annually.

A cost effectiveness analysis of these methods was used to select control options for field testing. The cost of controlling emissions from the waste dump activi-

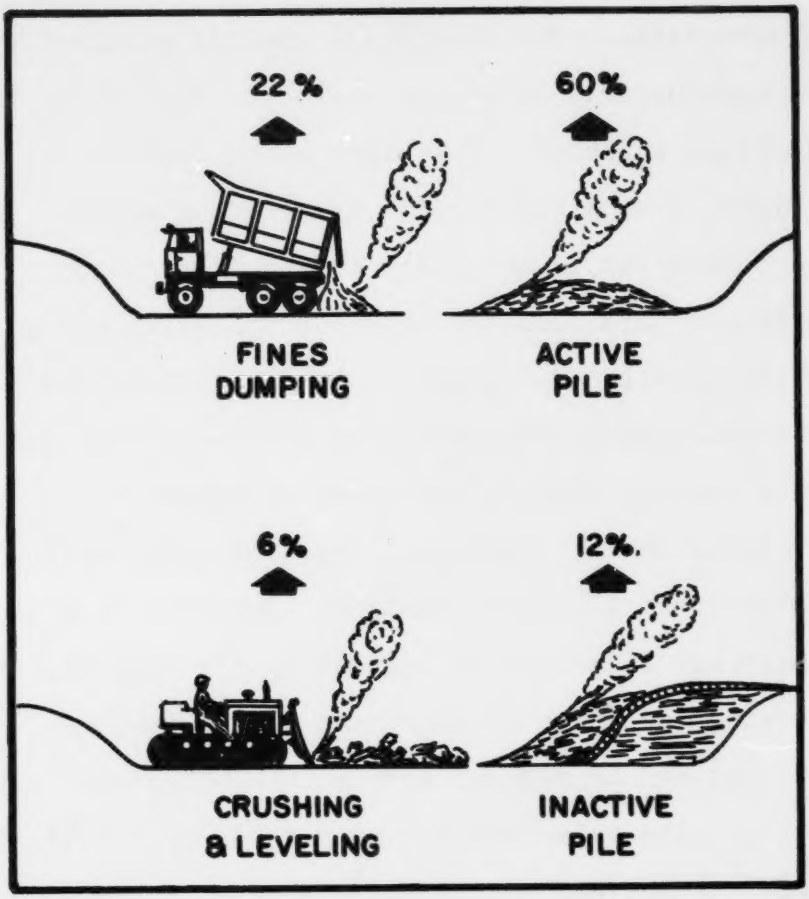
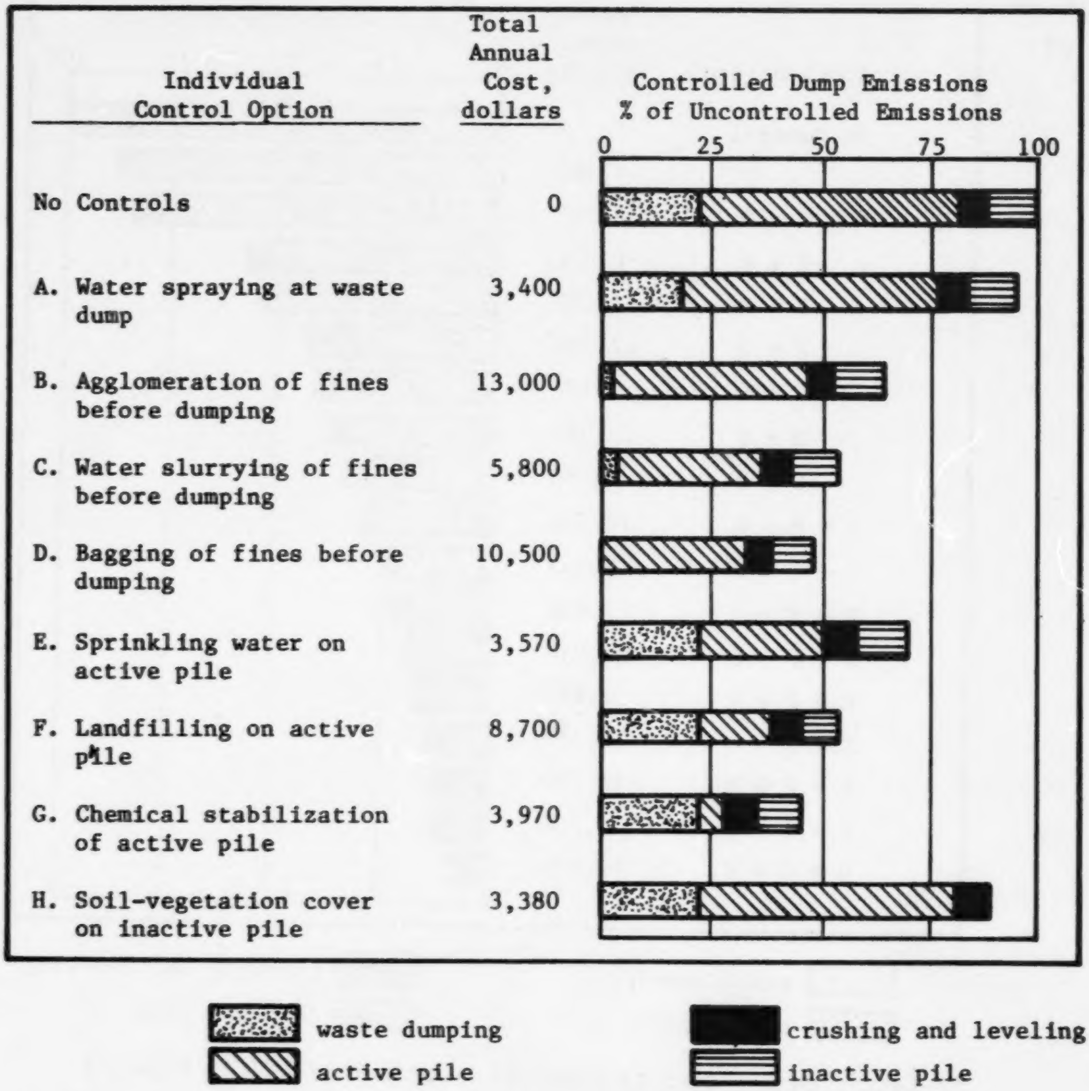

22 %
60%
FINES DUMPING
ACTIVE PILE
6%
12%.
CRUSHING & LEVELING
INACTIVE PILE

FIGURE I

PRIMARY DUMP ASBESTOS EMISSION SOURCES AND THEIR RELATIVE EMISSION RATES ties were estimated by invoking a model plant with a daily production of 250 metric tons, a daily disposal rate of 13.2 metric tons of aggregate waste, and 0.9 metric tons of baghouse fines. The techniques available to reduce emissions vary considerably in annual costs, as well as in the emission reductions achieved. The eight basic control options shown in Figure 2 were evaluated. These eight control options were considered individually and in combination to determine the lowest total cost methods for achieving the greatest overall emission reductions. The results of the cost analysis are summarized in Figure 3, and the least cost combinations of the control options are shown in Figure 4.

Based on this analysis, four emission control options were selected for field testing. Emission from the transfer of baghouse fines can be reduced by (1) bagging, or (2) slurrying the waste at the plant before dumping. Active pile emissions can be reduced with a chemical stabilizer, and inactive pile emissions can be reduced by a soil-vegetation cover. To prevent the inactive pile emissions from increasing each year with an annual increase in size of the pile, a permanent cover is mandatory.

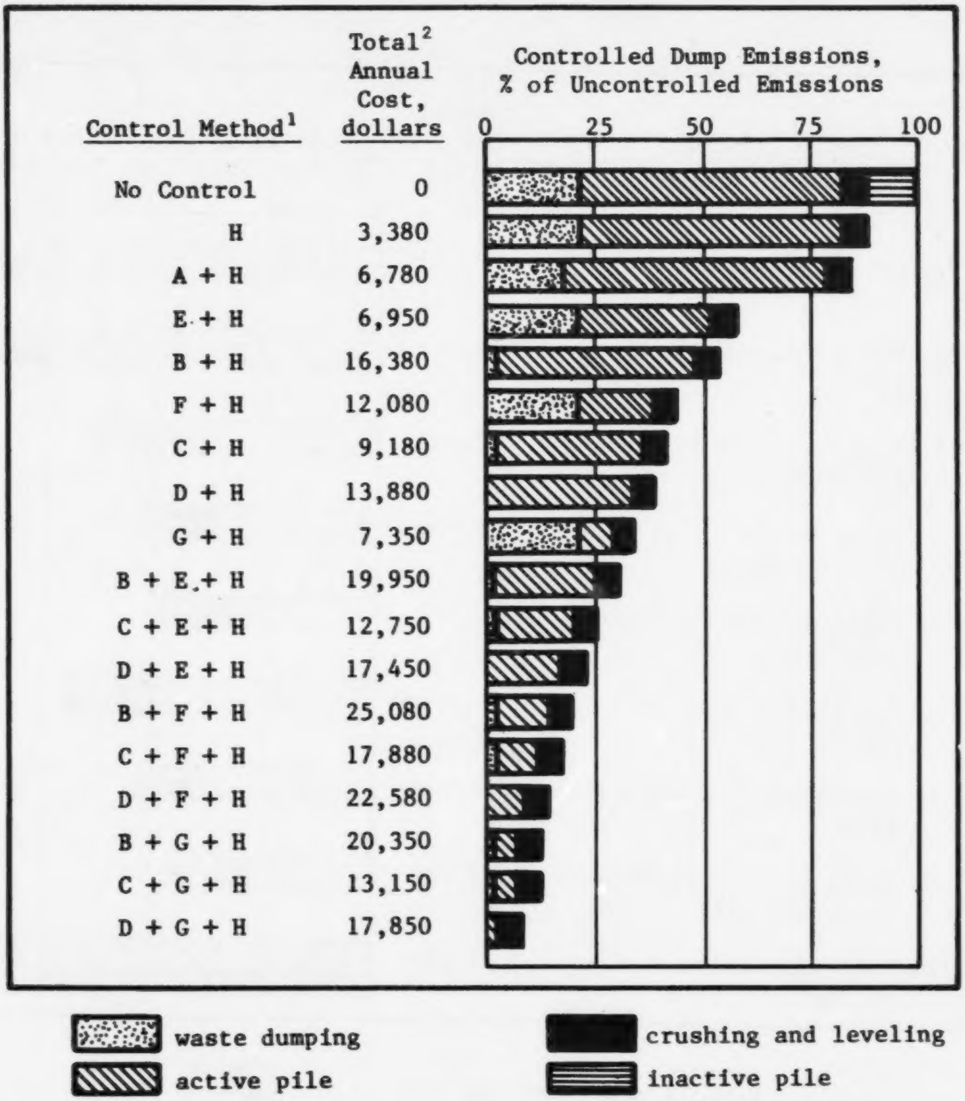
It was estimated that bagging would reduce dumping emissions by 100 percent, while the use of a chemical binder on the active pile would reduce its emissions by 90 percent, and a soil-vegetation cover would reduce the long-term emissions from the inactive dump by 100 percent. Application of the three control options in combination would reduce the emis-



[1] Based on plant production rate of 75,000 metric tons per year (250 metric tons per day).

Figure 2

INDIVIDUAL CONTROL MEASURES EFFECTIVENESS
AND THEIR APPLICATION COSTS



[1] Letter code refers to individual options listed in Figure 2.

[2] Based on plant production rate of 75,000 metric tons per year (250 metric tons per day).

Figure 3

COMBINATIONS OF EMISSION CONTROL OPTIONS -- THEIR EFFECTIVENESS AND THEIR APPLICATION COSTS

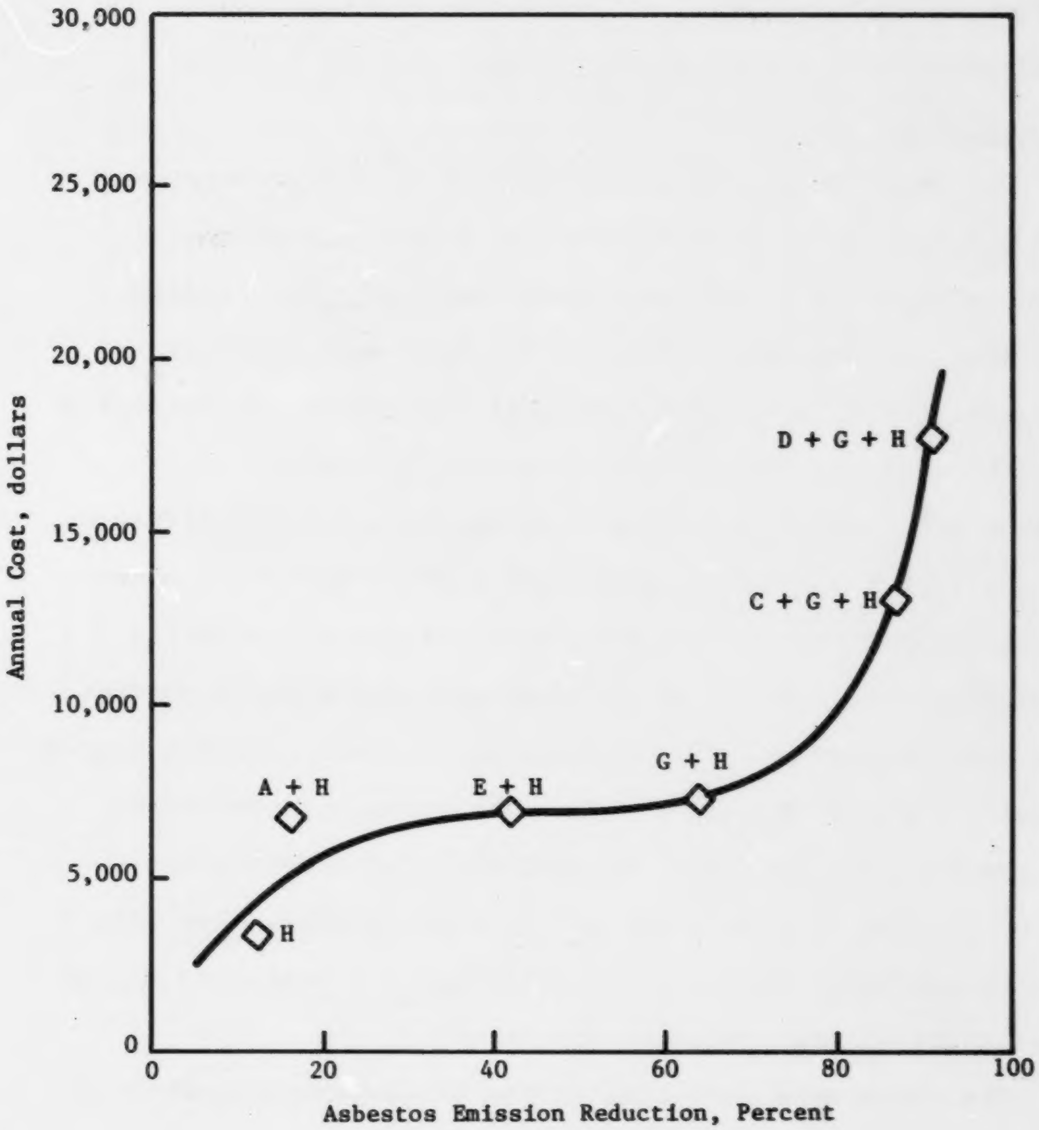


Figure 4

LEAST COST COMBINATIONS OF EMISSION CONTROL OPTIONS
(For description of individual control options,
see Figure 2)

sions by 91 percent at a total annual cost of $17,850 for the typical model plant. Substitution of slurrying for bagging in the dumping would reduce the combined control to 87 percent at a much reduced annual cost of $13,150.

FIELD TEST OF OPTIONS

The separate contributions of each of the primary sources were measured in field tests and the effectiveness of the controls selected to mitigate their emissions was studied. Following the recommendations of the cost effectiveness analysis, field tests were conducted with emission controls on only three of the four primary sources. Slurrying and bagging were tested for fines dumping; chemical stabilization was tested for the active pile; and a soil-vegetation coverage was tested for the inactive pile. Aggregate crushing is difficult to control at the dump and expensive to conduct as a plant operation. It is, however, a minor emission source overall. This is because, although obvious high emissions are created, the operation is conducted for only a short period of time -- once every one to three months. For this reason, aggregate crushing and leveling were monitored in the field tests without emission controls.

The tests were conducted at the Johns-Manville asbestos cement pipe plant located at Denison, Texas. The on-site location offered easy haulage of waste materials and cover soil, reasonable site security, and the availability of labor to maintain the piles and perform periodic tests.

FUGITIVE EMISSIONS MITIGATION

Field samples were collected and emissions monitored from the following transfer activities:

- dumping of fresh, dry fines
- dumping of fines as a slurry
- dumping of fines in plastic bags
- crushing of waste pipe
- leveling of waste
- dump background

The emissions were collected with high volume particle samplers and particle counters. The high volume samplers, in an upwind-downwind array, collected emission samples which were later examined for asbestos and analyzed for elemental composition, mass concentration, and fiber concentration. The particle counters gave real time data of the emission cloud concentration from the dump activities and the mitigation in the emissions by use of controls.

Table 2 gives some typical asbestos concentrations found near the dump while various activities were taking place. Data obtained from the transmission electron microscope operating at a magnification of 20,000X includes all fibers greater than 0.06 μm in length, while from the optical microscope, only those fibers greater than 5.0 μm in length were measured. Atomic absorption was used to estimate the mass concentration of asbestos which is given in units of nanograms per cubic centimeter.

Table 2

TYPICAL WASTE DUMP AMBIENT AIR ASBESTOS LEVELS MEASURED BY ELECTRON MICROSCOPE, OPTICAL MICROSCOPE, AND ATOMIC ABSORPTION

Activity	Distance m	Asbestos Concentration Electron Microscope Fibers/cm^3	Optical Microscope Fibers/cm^3	Atomic Absorption ng cm^3
No Activity	At Dump	1.2	0.05	0.003
Pipe Crushing	90	22.3	0.25	0.032
Waste Leveling	35	10.9	0.30	0.046

The contribution from the waste emission sources are shown in Table 3. These results were calculated from atomic absorption analyses of air samples collected at the dump. The greatest contribution to the asbestos emission comes from the active pile. In decreasing order and significance, the others are: waste dumping, inactive pile (assuming annual burial) and the crushing and leveling

Table 3

FUGITIVE ASBESTOS WASTE EMISSION ESTIMATES BASED ON FIELD MEASUREMENTS

Emission Source	Emission Rate during Active Emission kg/yr	Annual Emission Rate kg/yr
Active Pile	1,100	1,100
Dumping	1,300-6,300	90-430
Inactive Pile	230	230
Crushing & Leveling	500-6,300	6-70
Total		1,400-1,800

operation. The relative contribution from each of the sources is in good agreement with the original estimates.

Both the dumping and the crushing and leveling operations show much higher active emission rates than the active pile does, but due to the occassional nature of these activities, the annual emission rates are considerably lower. For the crushing and leveling the emission rate was less than 5 percent, while dumping gave between 5 percent to 30 percent of the annual waste dump asbestos emissions. Application of the control measure of bagging and slurrying reduced dust emissions by more than 95 percent for the dumping operation.

STABILIZATION OF WASTE PILES

Two options were used to demonstrate the stability of waste pile emissions controls. They were tested in the field over a period of seven months. Chemical stabilization was tested for the active pile. A permanent cover is not recommended for active pile because it is still subject to frequent additions, vehicular traffic, and movement of waste on the pile. Inactive waste piles, on the other hand, are sections of the dump which are filled and have been abandoned. For inactive piles, a revegetated soil cover was tested.

Recent interest in mineral waste stabilization has been the source of many new agents for chemical stabilization. A candidate for field testing was chosen based on limited laboratory tests for physical strength and durability. A resin stabilizer was selected which ranked near the top in laboratory tests. Convenience in mixing and ease of application were important criteria in the final selection. The stabilizer was applied on the test pile with a sprinkler at the rate of 0.45 l/m^3.

In general, it was observed that the chemically treated pile was stabilized very effectively. The stabilizer adhered well to the waste particles and reached a steady concentration level within the surface of the pile which was not removed after seven months of weathering by heat, cold, wind and rain. Surface moisture tests showed that the presence of the stabilizer did not affect the water retention in the top surface. The ability to retain water is important since moisture is very effective in reducing surface emissions.

The inactive test pile was covered with a 30 cm thick layer of sandy loam from a nearby area. The soil was fertilized and broadcast seeded with a mixture of species similar to those native to the area. A straw mulch was spread on the pile surface at a rate of 0.45 kg/m^2 and lightly crimped in to keep it from being blown away. The straw provided good, inexpensive protection for the establishment of the vegetative cover. Moisture for germination and establishment was provided with a sprinkler system during the initial six weeks.

It was demonstrated that, given a sufficient depth of soil and adequate fertilization, a stable, vegetative cover can be developed on the highly alkaline, non-fertile asbestos waste. A plant cover of 70 percent is regarded as a minimum to stabilize a waste pile against erosion by weather action. In fact, a 95 percent cover was developed. The high pH and electrical conductivity associated with the asbestos cement waste can be tolerated if a sufficiently deep soil cover is used and care is taken to avoid mixing of the waste with the soil as it is deposited on the pile.

The work described in this paper represents a portion of a study supported by the Environmental Protection Agency under Contract Number 68-02-1872.

FUGITIVE EMISSIONS FROM CHEMICAL FERTILIZER MINING

By

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ABSTRACT

FUGITIVE EMISSIONS FROM CHEMICAL FERTILIZER MINING

This paper summarizes the results of field testing programs to develop emission factors for dust generated in the storage, loading, and handling of potash and phosphate rock. The samples collected were analyzed for composition and particle size distribution, and emission factors were developed both for the total mass of emissions for the overall process and for unit operations. Visual observations were utilized to evaluate various control measures which have been taken over the years by the industry. Data has been collected from sampling programs other than those conducted by Monsanto Research Corporation and the results compared and combined to give additional perspective to the emissions and the extent of control obtainable. The major obstacles in application of control technology lie in converting existing facilities to accommodate the dust control equipment. Some of the problems include door and hopper configuration, rail car height, length of duct runs from dust area to control device, and the settling and compacting characteristics of the dust to be handled. Several examples of the latest control techniques which are effective are described.

FUGITIVE EMISSIONS FROM CHEMICAL FERTILIZER MINING

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Foreword

Monsanto Research Corporation is currently involved in a program aimed at providing the preliminary data necessary for future planning of EPA action in developing control technology for emissions from mining operations. Mining emits air pollutants in a primarily nonpoint manner. These sources are generally large and diffuse in nature and are often comprised of several fugitive emission points. Consequently, their source strength is quite difficult to assess accurately.

The area covered by this paper is the mining and beneficiation of phosphate rock and potash. These processes are responsible for most of the emissions from the chemical fertilizer raw materials industry. The report addresses the following questions:

1. What are the sources of air emissions?
2. Are they fugitive or stack emissions?
3. What is the magnitude of the emissions?
4. What control technology is currently in use?
5. What are the future trends in control technology?

Background

Vegetation requires several materials for adequate nutrition. The four major plant food elements are nitrogen, phosphorus, potassium, and sulfur.[1] Of these only nitrogen, phosphorus, and potassium are needed by the plant in relatively large quantities. The primary function of the fertilizer industry is to supply these nutrients.[2] Of these three, only the natural minerals of phosphorus and potassium are of commercial importance. Manufactured nitrates, such as urea, are acceptable substitutes. Therefore, a discussion of the air emissions produced by the mining and beneficiation of materials for the chemical fertilizer industry needs to consider only two minerals. These are phosphate rock and potash.

Phosphate Rock

Phosphate rock is the common term used for most commercial phosphate raw materials. At least 90% of the world's annual phosphate rock supply is typically converted into phosphorus and phosphoric acid intermediates of which at least 85% of the world supply is annually consumed in fertilizers. U.S. production of marketable phosphate rock has grown from 18 million metric tons in 1960 to about 44 million metric tons in 1975, or about 6 percent per year.

Phosphate ore mining and processing is carried out in four different regions of the United States. These areas and their contribution to the total output are:

- Florida 78%
- Western States (Montana, Idaho, Wyoming, and Utah) 12%
- North Carolina 5%
- Tennessee 5%

In Florida the deposits are concentrated primarily in a relatively small area: a total of about 3½% of Florida's land.[3] The phosphate that comes from this limited area provides approximately one-third of the whole world's production.

Of the two available rocks, pebble and hard rock, pebble phosphate is the more important. It has a P_2O_5 content around 30%. Hard rock has been of little commercial value because of low phosphate concentration and/or high mining and processing costs.

The actual ore is a sand/clay/phosphate matrix of about equal portions. Table 1 gives analyses for P_2O_5, CaO, F, and U of Florida phosphate rock.[4]

TABLE 1. ANALYSIS OF PHOSPHATE ROCK: FLORIDA, %[4]

	Bone Valley formation		Hawthorne formation[a]	
Composition	Pebble	Concentrate	Pebble	Concentrate
P_2O_5	30.8	32.5	23.5	29.9
CaO	43.7	43.2	40.0	44.8
F	3.4	3.6	2.7	3.3
U	0.015	0.010	0.009	0.007

[a] Lies beneath the Bone Valley formation.

Most phosphate rock is mined by open-pit methods. Some locations in the West mine by underground techniques; however, they account for only a minor part of the total production. The common practice in Florida is to strip the overburden with electric-powered draglines and place it in windrows alongside the cut.

No sampling for the dragline source in Florida has been done. However, some estimates have been made on this fugitive emission from other source assessment studies on mining.[5] Dust emissions from surface mining of coal were measured by MRC as 0.8 g/kg (0.17 lb/ton) of overburden removed. Battelle indicated that overburden removal was the largest emission source at strip mines and estimated 0.5 k/kg (.1 lb/ton).[6] Engineering Research and Technology, upon providing input on the air quality aspects of coal development in northwest Colorado, proposed an emission factor of 0.024 g/kg (0.048 lb/ton) of overburden removal, including a correction for climatic conditions and control measures (watering) at the mines.[7]

Overburden removal for phosphate rock mining is believed to be much less of a fugitive dust source than in coal mining because much less overburden material is handled; the average overburden depths in Florida are about 6 m (20 ft) versus up to 60 m (200 ft) for coal mining. Also, phosphate rock deposits in Florida are generally mined in areas where the water table is near the surface. Because the moisture content of the overburden is high, less dust is produced.

An emission factor for the overburden removal of phosphate rock definitely lies toward the bottom of the range (0.048 to 0.10 lb/ton of overburden)[5] offered by PEDCo. PEDCo estimated particulate emissions from dragline operations at an open pit copper mine in Butte, Montana.[8] The emission rate per ton of ore mined was 0.004 g (0.008 lb). This excavation area was noted to be moist and nondusting. Although actual measurements were not taken at phosphate rock mines, it is felt that an emission factor of this order of magnitude is representative for the mining of the ore.

Since the stripping of overburden and mining of matrix is carried out under somewhat "wet" conditions, industry does not consider this a source of air emissions. Therefore, they have no controls on this operation and do not expect a future need.

After the overburden is removed, the ore is placed into sluice pits where hydraulic monitors break up the ore. It is subsequently pumped to the beneficiation plant. Each company's beneficiation methods differ slightly and are dependent on the characteristics of the matrix. In each case, however, it is a wet beneficiation process and therefore is not a source of air emissions.

The beneficiated rock is transferred to open storage piles. As this material is also moist, no controls are used or expected in the future although some emissions do result from the operations.

Typically, the moist material is conveyed by an underground belt operation to a rotary dryer. The dust from the driers is handled by cyclone-wet scrubber combinations. (One operation uses a rotary drier which has a cyclone scrubber followed by twin wet scrubbers.) In this way, the emission becomes a stack emission. Collection efficiencies of these control devices are greater than 95%, and no further controls are expected in the future. The material is sometimes ground at this point. However, the plant in our study did the grinding under wet conditions. One plant which was visited does not use a grinding operation at all.

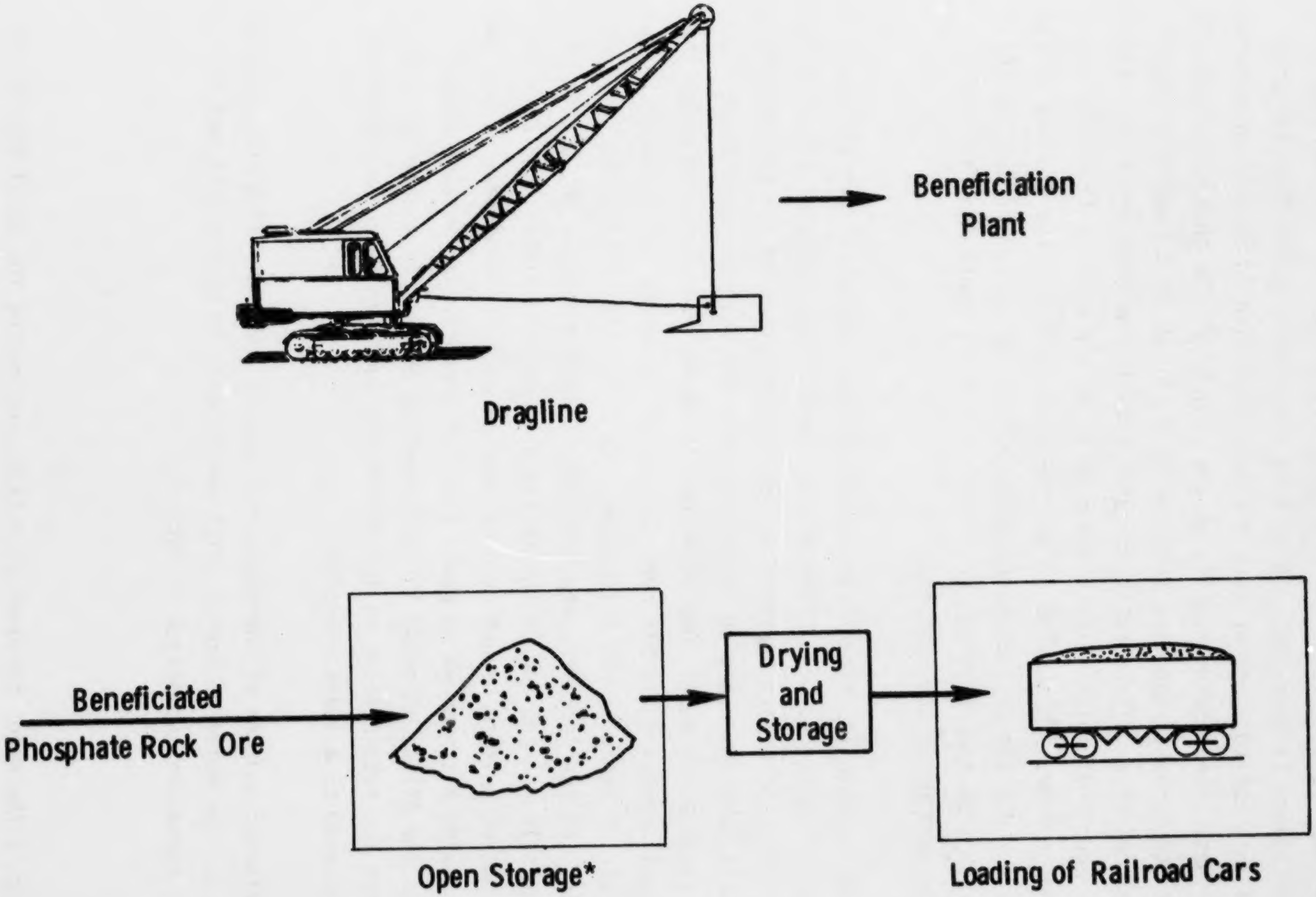
From the dryer, the material is transferred to storage silos. Control devices on rock transfer junctions are typically scrubbers. The average collection efficiency is over 95%. It is from the storage silos that the rock is dropped into railroad hopper cars for transportation to fertilizer manufacturing centers. The loading facilities are typical of the phosphate industry. Loading is accomplished manually from overhead storage by an operator standing at the roof level of the railroad car. Usually the drop areas have flexible rubber couplings which deliver the rock to within about 2 ft of the top of the loading door. This helps direct the rock; however, the problem in the loading is not dusting caused by the drop, but by the pickup of dust in the displaced air from the railroad car. This is a dusty operation, and the industry is working on the problem.

Companies have installed extensive ductwork systems which capture the dust and exhaust it to a scrubber. However, as noted by one representative of the industry, it is not always possible to get the operators to use the equipment properly. It involves clamping enclosures onto the railcar doors tight enough to capture the dust. One plant uses a mechanized system in which the ends of eight loading ducts fit over the top of the eight railcar doors. The displaced air is exhausted to a scrubber. In older facilities, this may not be possible. At one location, the available headroom between the bottom of the storage silo and the top of the railcars is very confining, and cars are typically not of uniform height or door configuration. Therefore, it was necessary to design a system which would load the cars from an outside hopper adjacent to the silos, allowing for more working space. In either case, it appears that the future trend is to contain the fugitive emission, enabling it to be treated as a stack emission.

The air emission sources of phosphate rock mining and processing are pictured in Figure 1. The emission factor which corresponds to each source and the discussion above are summarized in Table 2.

Potash

Agriculture is the major consumer of potash, accounting for about 95% of the total consumption in the U.S. The percentage is even higher for the rest of the world.


Beneficiation
Plant
Dragline
Beneficiated
Phosphate Rock Ore
Drying
and
Storage
Open Storage*
Loading of Railroad Cars

*Emission factor not provided.

Figure 1. Selected Phosphate Rock Sources

TABLE 2. AIR EMISSION SOURCES OF PHOSPHATE ROCK MINING AND BENEFICIATION

	Dragline					
	Stripping of overburden	Mining of the ore	Drying	Silo storage	Loading	Total
Emission factor, g/kg (lb/ton)	.25 (.05)	.0004 (.0008)	.071 (.142)	.105 (.142)	.161 (.322)	.362 (.725)
Existing control devices	None	None	Cyclone and wet scrubbers	Scrubbers	Enclosure	
Effectiveness of existing control devices			>95%	>95%	-[a]	
Future trends of control devices	None	None	None	None	Exhaust fugitive dust to control device	

[a] Not available.

The United States' portion of production in North America has remained about the same in volume (2.3 million metric tons K_2O in 1975), but the share of production has decreased from 100 percent in 1960 to about 30 percent in 1975, as the vast resources of Saskatchewan were brought onstream.

Potash, like phosphate rock, is also produced in four different geographical areas. However, four different processing methods are used. These areas, their types of operation used, and their share of the total output are presented in Table 3.

TABLE 3. U.S. PRODUCTION AREAS OF POTASH[9]

	Type of operation	Total percentage of output
New Mexico Carlsbad	Conventional mining, flotation. (One company dissolves ore in brine, (crystallizers)	81
Utah Great Salt Lake	Solar evaporation of natural or lake brines, flotation	6
Utah Moab	Underground solution brine, solar evaporation, flotation	6
California Trona (Searles Lake)	Steam evaporation of lake brine, vacuum crystallizers	7

The area of interest for this report is in New Mexico due to its large share of the output. Sylvinite ore, a mechanical mixture of sylvite (KCl) and halite (NaCl), is a natural ore for potassium.[10] This ore is found in commercial quantities in the Permian Basin region near Carlsbad, New Mexico. Table 4 shows the typical composition of potash ore in New Mexico.

Potash ores are usually processed in refineries adjacent to the mines.[4] The bedded deposits of New Mexico are all mined underground in a manner similar to that used for coal. There are two processes employed in the Carlsbad area refining facilities. One is used for recovery of potassium chloride from sylvinite ore and the other for converting langbeinite ore to potassium sulfate.

TABLE 4. COMPOSITION OF POTASH[4]

Area	Composition, %	
Carlsbad - New Mexico	Polyhalite	
	K_2SO_4	21.93
	$MgSO_4$	15.15
	$CaSO_4$	34.29
	Anhydrite	
	$CaSO_4$	8.17
	NaCl	12.91
	H_2O	4.53
	Fe_2O_3	2.29
	$MgCO_3$	0.73
	Total mineral	
	Polyhalite	75.9
	Halite	12.9
	Anhydrite	8.2
	Others	3.0
Eddy County - New Mexico	Langbenite	
	K_2O	22.37
	MgO	19.15
	SO_3	57.44
	Na_2O	0.48
	Insoluble in water	0.05

Most of the potassium chloride is recovered from sylvinite ore by flotation methods. The essentials of this process are to treat the ore with a hydrophobic material (e.g., an aliphatic amine) which will selectively coat one of the constituents (the KCl) of the ore. Air is then bubbled through the slurry, and the air bubbles attach themselves to the coated particles and float them to the surface, while the uncoated particles sink. A process flowsheet is given in Figure 2. On a large scale and particularly with high-analysis ores, the flotation process is much cheaper than one involving dissolution and crystallization. However, available resources of the high-grade,

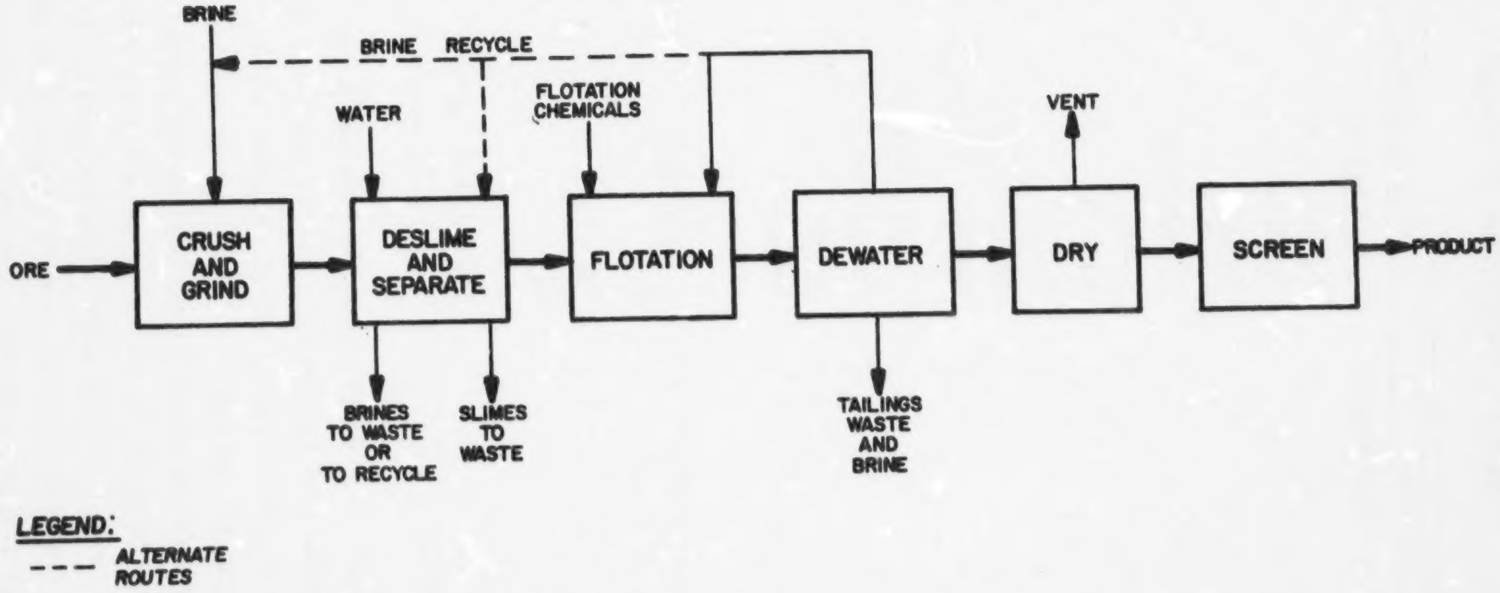

BRINE
BRINE RECYCLE
WATER
FLOTATION CHEMICALS
VENT
ORE
CRUSH AND GRIND
DESLIME AND SEPARATE
FLOTATION
DEWATER
DRY
SCREEN
PRODUCT
BRINES TO WASTE OR TO RECYCLE
SLIMES TO WASTE
TAILINGS WASTE AND BRINE
LEGEND:
ALTERNATE ROUTES

Figure 2. Potassium Mining and Processing from Silvinite Ore

low-clay ores that have been mined and concentrated during the past 40 years are declining in grade, while the ore to be mined in the future has become more difficult to beneficiate because of increased clay content which interferes with flotation.

Research by industry and government has been in progress for several years to fashion systems involving flotation and leaching-crystallization processes for treatment of the low-grade resources. One plant currently uses a leaching-crystallization process, while the remaining plants that process sylvinite ore use flotation.

Langbeinite is a natural sulfate of potassium and magnesium, $K_2Mg_2(SO_4)_3$, usually intermixed with sodium chloride. Two facilities at Carlsbad process langbeinite ore. This ore is mixed, crushed, and dissolved in water to which potassium chloride is added. Partial evaporation of the solution produces selective precipitation of K_2SO_4 which is recovered by centrifugation or filtration from the brine liquor, dried, and sold. A simplified process flowsheet is given in Figure 3.

The air emission data for potash refinery activity near Carlsbad, New Mexico is presented in Table 5. Some explanation of the table is necessary. The seven companies (A-G), which operate in the vicinity of Carlsbad, New Mexico, are listed. The two sets of emission factors, based on production and capacity, are presented to equalize any production irregularities (such as E's cutback on production due to construction). A comments column is provided to explain the deviation among the numbers. Except where designated, the emission factors represent the total particular emission of the refineries. These emission factors account for operations such as rock transfer, grinding, screening, drying, bagging, loading, and (in B and F's case) evaporation.

The major source of emissions is the drying operation, which is employed at all locations. At present, the use of dry cyclones is the most evident form of control technology. They are in use not only at drying locations, but at other points of the process such as milling, screening, and bagging. A feel for the amount of emission caused by drying can be gained by looking at A and E's emission factors.

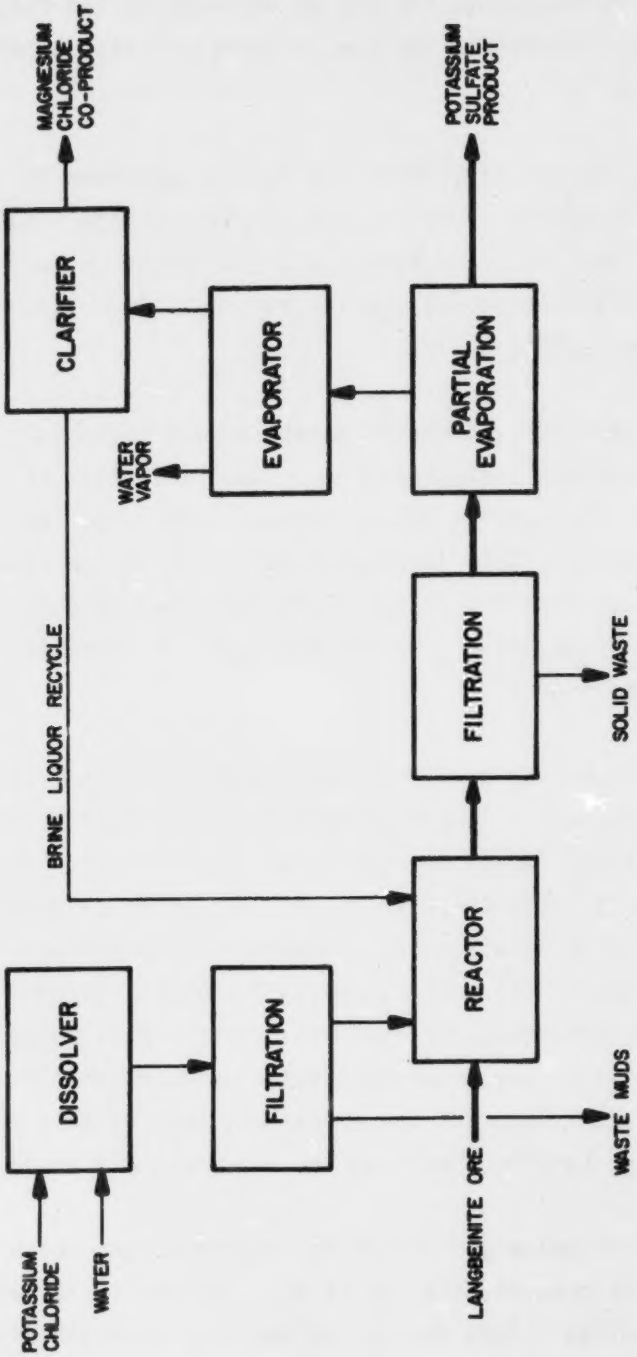

POTASSIUM CHLORIDE
WATER
DISSOLVER
FILTRATION
LANGBEINITE ORE
WASTE MUDS
REACTOR
BRINE LIQUOR RECYCLE
FILTRATION
SOLID WASTE
PARTIAL EVAPORATION
POTASSIUM SULFATE PRODUCT
EVAPORATOR
WATER VAPOR
CLARIFIER
MAGNESIUM CHLORIDE CO-PRODUCT

Figure 3. Langbeinite Mining and Processing

TABLE 5. NEW MEXICO POTASH PARTICULATE EMISSION DATA

Company	Annual[11] emission rate, g/s (lb/s)	Average K_2O content, %	Ore processed, 1975 production, kg/yr (tons/yr)	Emission factor based on production, g/kg (lb/ton)	Ore processed, current[10] capacity, kg/yr (tons/yr)	Emission factor based on capacity, g/kg (lb/ton)	Comments
A	22.58 (0.0497)	40	1.655×10^9 (1,820,000)	0.430 (0.860)	2.121×10^9 (2,333,333)	0.336 (0.672)	Dryer emissions only
B	318.66 (0.7019)	8	3.625×10^9 (3,987,500)	2.772 (5.544)	4.318×10^9 (4,750,000)	2.327 (4.654)	Includes a separate salt operation
C	10.86 (0.0239)	16	1.932×10^9 (2,125,000)	0.177 (0.354)	1.989×10^9 (2,187,500	0.172 (0.344)	Uses a leaching operation
D	62.82 (0.1384)	18	1.944×10^9 (2,264,706)	1.019 (2.038)	2.778×10^9 (3,055,555)	0.713 (1.426)	-[a]
E	26.8 (0.0590)	14	0.468×10^9 (514,286)	1.806 (3.612)	1.753×10^9 (1,928,571)	0.482 (0.964)	Dryer emissions only Cutback due to construction
F	87.51 (0.1928)	11	1.653×10^9 (1,818,182)	1.670 (3.340)	2.149×10^9 (2,363,636)	1.284 (2.568)	-[a]
G	91.97 (0.2026)	23	2.202×10^9 (2,422,727)	1.318 (2.636)	2.273×10^9 (2,391,304)	1.334 (2.668)	-[a]

[a] Not applicable.

Time basis: 31,536,000 seconds/yr

Another major source of particulate emission appears at the locations where langbeinite ore is processed by an evaporation step. Ozark submerged-combustion evaporators are in use at these plants. They consist of a tank to hold the liquid, a burner and gas distributor that can be lowered into the liquid, and a combustion-control system. One difficulty frequently encountered in the use of submerged-combustion evaporators is a high entrainment loss. Prior particle size measurements on a plant's Ozark evaporator showed 100% of the particles to be less than 7 microns. These would all remain suspended. A study is currently in progress to assess the application of Monsanto's Brink® fine particle eliminators to the problem.

According to the New Mexico Environmental Improvement Agency, it would appear that most all of the existing potash refineries will need to control their present emissions. At this point, the agency is investigating different types of control technology and their costs.[11]

Sampling and Analytical Methodology

A Gaussian plume equation was used to estimate the fugitive dust source strength from ground level, ambient hi-vol air samplers. Since the dispersion equation gives a time-averaged description of the concentration field, a number of receptors were used, as shown in Figure 4. The following rationale applies: (1) the position of the sampler determines ambient dust levels, and (2) wind direction and velocity were not constant and affect time-averaging results. The positioning of samplers eliminated the need to correct for time varying concentrations.

Sampler 1 was the primary source composition strength estimator and was located as close to the source as possible. Sampler 3 was required for correlations with downwind power law decay. Samplers 2 and 4 were required for correlations with lateral dispersion estimates. Sampler 0 was used as a blank to compensate for other dust sources upwind of the site under investigation.

A portable mechanical meteorological station gave the remaining parameter, wind speed. The azimuth was monitored throughout the sampling period. The

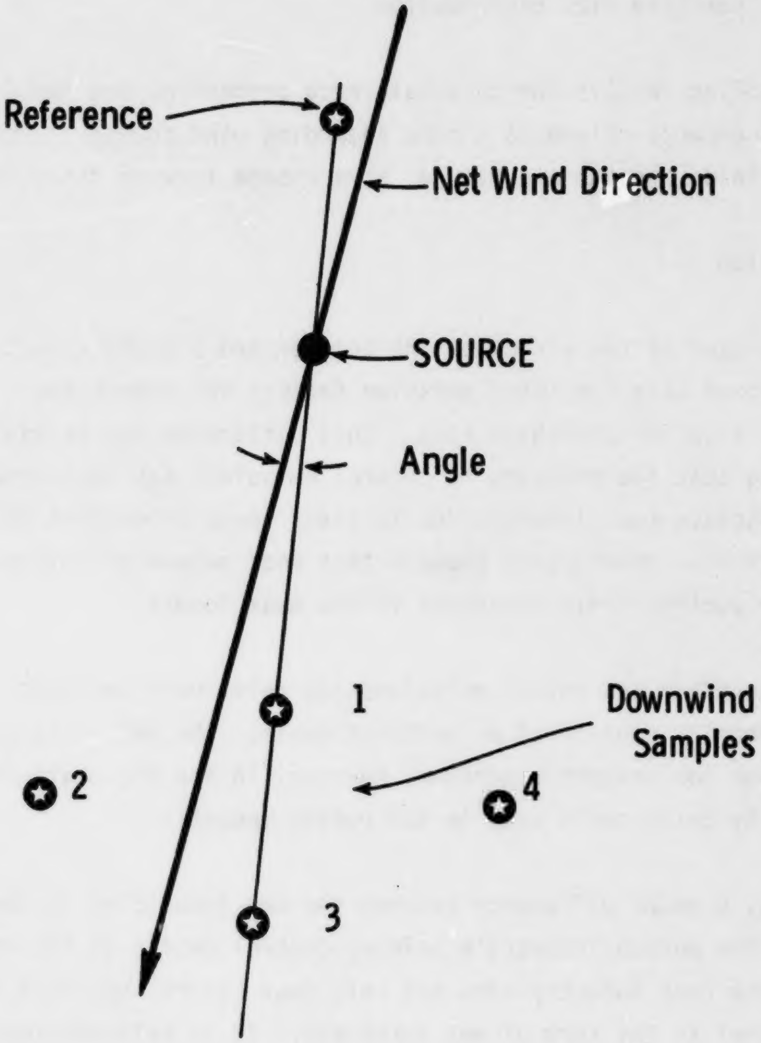

Reference
Net Wind Direction
SOURCE
Angle
1
Downwind
Samples
2
4
3

Figure 4. Sampler Positions

filter from Sampler 1 was analyzed by X-ray fluorescence techniques and compared to source materials for composition. A particle count was also made via optical microscopy to check for fibers and to give a different perspective to particle size distribution.

The sampling results for phosphate rock processing are summarized in Table 6. In the comments column is a note regarding wind change. Excessive wind shift was defined, through experience, as a change in wind direction greater than 20°.

Conclusion

A comparison of the air emissions between the phosphate rock and potash industries shows that the total emission factors for potash are 2 to 4 times greater than for phosphate rock. This difference may be explained by understanding that the pressure to control emissions has been somewhat greater on the phosphate rock industry due to their large production and concentration in one area. However, it appears that most potash refineries will have to further control their emissions in the near future.

Both phosphate and potash emissions are relatively nontoxic; in fact, they are generally considered as nuisance dusts. The danger is particle size. This does not present a problem, however, in the phosphate industry and is currently being dealt with in the potash industry.

Finally, a major difference between the two industries is the methods of control. The potash industry's primary control device is the dry cyclone. The phosphate rock industry uses not only that control but also secondary stages of control in the form of wet scrubbers. It is believed that, with the exception of the Ozark evaporators, the necessary control technology exists for the potash industry.

TABLE 6. PHOSPHATE ROCK PROCESSING

Material	Source sample, %	Run 3, %	Run 5, %	Run 6, %
Phosphorus	32.6	25.5	25.6	22.4
Sodium	0.40	-[a]	-[a]	-[a]
Magnesium	0.09	0.2	0.73	0.75
Aluminum	2.11	2.5	2.93	3.19
Silicon	5.45	4.1	13.9	5.3
Sulfur	-[a]	-[a]	-[a]	-[a]
Potassium	0.14	0.08	0.07	0.11
Calcium	41.4	60.0	49.8	59.5
Titanium	1.10	0.16	0.15	0.21
Chlorine	-[a]	-[a]	-[a]	-[a]
Chromium	-[a]	-[a]	-[a]	-[a]
Manganese	0.11	-[a]	-[a]	-[a]
Iron	2.47	1.6	1.46	2.13
Fluorine	3.82	5.8	5.1	6.4

	Minutes run	Total particulate emission rate	Standard deviation	Confidence limits
Run 1	232	169.3 lb/hr	±67.6 lb/hr	±124.4
Run 2	265	-[b]	-[b]	-[b]
Run 3	350	82.16 lb/hr	±40.82 lb/hr	±75.0
Run 4	320	250.2 lb/hr	±166.6 lb/hr	±306.1
Run 5	245	55.6 lb/hr	±5.35 lb/hr	±9.83
Run 6	239	126.6 lb/hr	±86.1 lb/hr	±158.2

	Particle size distribution	Emission factor	Comments on run
Run 1	10.11% less than 7 μ	0.434 lb/ton	-[c]
Run 2		-[b]	Excessive wind change
Run 3		0.210 lb/ton	Storage
Run 4		0.639 lb/ton	Total
Run 5		0.142 lb/ton	Drying
Run 6		0.322 lb/ton	-[c]

[a] None detected. [b] No good. [c] Not applicable.

Note: Compositions were calculated after drying.

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FUGITIVE EMISSION CONTROL IN THE IRON & STEEL INDUSTRY

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Abstract

Fugitive Emissions related to the various steps in the Iron and Steelmaking process have been largely ignored or tolerated in the past mainly due to light concentrations as well as the difficulty of collecting these emissions. However, today with larger production units creating more concentrated emissions, they can no longer be ignored. With present air pollution control regulations, virtually no visible emissions are allowed from the buildings.

Since air pollution is associated with practically all steps of Iron and Steel Production, the related air pollution control equipment is an important factor in all of these operations. A production process may become obsolete if it is not capable of meeting today's stringent air pollution control requirements.

Because of the emphasis by regulatory authorities today for complete emission control during the Basic Oxygen Steelmaking Process, the limited scope of this paper will concentrate on Fugitive Emission Control in this area, but will also encompass the other main metallurgical production processes.

FUGITIVE EMISSION CONTROL IN THE IRON & STEEL INDUSTRY

INTRODUCTION

FUGITIVE EMISSION CONTROL DURING THE BASIC OXYGEN STEELMAKING PROCESS

- Hot Metal Charging
- Scrap Charging
- Tapping
- Slagging
- Puffing During Oxygen Blow

HOT METAL RELADLING

FLUX HANDLING

ELECTRIC ARC FURNACE

- Charging and Tapping Emission Control
- Furnace Aisle Enclosure

CONCLUSION

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Air Pollution Control Systems
Pennsylvania Engineering Corp.
Pittsburgh, Pennsylvania

Fig. 1 Hot Metal Charging for the Basic Oxygen Process.

Fig. 2 Schematic Arrangement and Design of BOF Furnace Enclosure.

Fig. 3 Schematic Arrangement Showing Components Effecting Fugitive Emission Control with Furnace Enclosure.

Fig. 4 Tapping Emission Control with BOF Furnace Enclosure.

Fig. 5 Recent BOF Shop Installation with Fugitive Emission Control.

Fig. 6 Hot Metal Charging Emission Control with Furnace Enclosure.

Fig. 7 Schematic Arrangement - Ladle Hood for Reladling Emission Control.

Fig. 8 Reladling Emission Control - Pouring through a Slot on Top of the Ladle Hood.

Fig. 9 Reladling Emission Control - Pouring through a Vertical Slot in the Ladle Hood.

Fig. 10 Schematic Arrangement - Electric Furnace Pollution Control System with Enclosed Furnace Aisle.

Fig. 11 Furnace Enclosure for Emission Control on Electric Arc Furnace.

FUGITIVE EMISSION CONTROL IN THE IRON & STEEL INDUSTRY

INTRODUCTION

Fugitive Emissions related to the various steps in the Iron and Steelmaking process have been largely ignored or tolerated in the past mainly due to light concentrations as well as the difficulty of collecting these emissions. However, today with larger production units creating more concentrated emissions, they can no longer be ignored. With present air pollution control regulations, virtually no visible emissions are allowed from the buildings.

Since air pollution is associated with practically all steps of Iron and Steel Production, the related air pollution control equipment is an important factor in all of these operations. A production process may become obsolete if it is not capable of meeting today's stringent air pollution control requirements.

Because of the emphasis by regulatory authorities today for complete emission control during the Basic Oxygen Steelmaking Process, the limited scope of this paper will concentrate on Fugitive Emission Control in this area, but will also encompass the other main metallurgical production processes.

Total Fugitive Emission Control can be broken down into two (2) main components:

1. Collection of the Fugitive Emissions.
2. Gas Cleaning after the fumes have been collected.

With present technology, the alternatives available for collecting the emissions generated during the main metallurgical production processes are limited and have many disadvantages. The ideal solution is to capture the emissions at their source. However, this is not always possible.

In new installations today where large volumes are involved, cleaning of Fugitive Emissions is done mainly with Dry Bag Filter ("Baghouse"). However, when it is possible to capture the emissions at their source with relatively low volumes or heat is a problem, Electrostatic Precipitators or High Energy Scrubbers may be the best solution for Gas Cleaning.

FUGITIVE EMISSION CONTROL DURING THE BASIC OXYGEN STEELMAKING PROCESS

Overall, a number of sources exist which generate Fugitive Emissions during the Basic Oxygen Process. Collection of these Fugitive Emissions has become more of a concern than the primary Gas Cleaning itself. This concern for Fugitive Emission Control is based on the difficulty of efficient fume collection at the emission source, since once the fume escapes into the building, it is almost impossible to control.

At the present time, twenty-seven (27) operating BOF/Q-BOP facilities in the United States are in violation of current air pollution control regulations for Fugitive Emissions and must bring these emissions under control in the near future.

In an effort to comply with current Air Pollution Control Regulations in the U.S., many systems of different design have been installed and are in operation today with varying degrees of success. They include partial or complete building evacuation by means of a canopy hood, local hoods close to the emission source, partial or full enclosures and various combinations of these systems. To successfully control Fugitive Emissions with a minimum expenditure, they must be collected at the source and not allowed to escape into the building.

Major sources of Fugitive Emissions in the Basic Oxygen Steelmaking Process are:

1. Scrap Charging
2. Hot Metal Charging
3. Tapping and Ladle Alloy Additions
4. Slagging
5. Puffing During Oxygen Blow
6. Hot Metal Reladling
7. Flux Handling

Other sources such as Ladle Transporting and Teeming also contribute to the Fugitive Emissions, but are minor in nature since they are low in volume and dissipate readily. They normally do not contribute to monitor emissions in the BOF Shop.

HOT METAL CHARGING

The worst condition occurs during charging of Hot Metal into the furnace which already contains scrap. The Hot Metal and the effect of the Hot Metal on the scrap both contribute to emissions during this period. Figure 1 shows the typical fumes generated when charging Hot Metal into the furnace. Test results have shown that fumes generated at this time are composed of approximately 35% Iron Oxide, 30% Kish and 35% others, with particulate size less than 100 microns and an approximate emission rate of 0.3 - 0.4 lbs per ton of Hot Metal poured.

Since the prime factors controlling fume generation during this period are the condition of scrap and the rate of Hot Metal poured, operating practice is a big factor in the amount of fumes generated.

SCRAP CHARGING

Scrap Charging itself is not a primary source of pollution, however, when the scrap contains a foreign substance such as dirt, paint or oil, it becomes a major pollution source when the Hot Metal is added. The quantities of pollution generated during Scrap Charging itself are minor compared to the fumes generated during Hot Metal Charging and can be minimized by scrap selection.

TAPPING

A dense fume normally results from the Tapping Operation itself and with ladle additions such as Ferro Silicon and Ferro Manganese, the magnitude of the problem increases. Fume composition here is dependent on the alloys employed but generally would consist of 75% Iron Oxide with particle size less than 100 microns and an average emission rate of 0.15 - 0.20 lbs per ton.

SLAGGING

Emissions from the Furnace Slagging Operation can be a major problem depending on the type of steel being produced which influences the slag volume and emission rate at this time. The method of killing the slag is also a factor which influences the emissions during the Slagging Operation. Fumes are generated inside the furnace at this time and continue with the Slag as it falls inside the Slag Pots below the charging floor. These emissions normally have a particle size less than 100 microns.

Slagging fumes are relatively cold and do not have the necessary thermal energy to cause the fumes to rise into an Overhead Canopy Hood making them difficult to capture.

PUFFING

Puffing during the Oxygen Blow occurs intermittently. When this occurs, generally small quantities of fume are emitted around the mouth of the furnace. This is not a major source of Fugitive Emissions, however, it does contribute to the total emission problem in the shop.

With present technology, the alternatives available for collecting the Oxygen Steelmaking Fugitive Emissions are:

1. Complete or Partial Building Evacuation.
2. Local Hoods (Fixed or Movable).
3. Furnace Enclosures.

Canopy Hoods for partial or complete building evacuation systems are operating in a number of shops with varying degrees of success. In most cases, this method is normally considered as a last resort due to the high capital expenditure and operating cost involved. These systems usually are given consideration by maintenance and operating personnel since they require minimum maintenance and do not restrict operating practices. However, disadvantages are the high volume requirements to achieve necessary collection efficiency due to the distance of the hoods from the emission source and the adverse effects of cross drafts in the shop which affect collection efficiency. Volume requirements here would be in excess of 1,000,000 CFM for partial or complete building evacuation.

The use of Local Hoods for collecting Charging Emissions is more effective than the Canopy Hood located in the Building Trusses since Local Hoods are in closer proximity to the emission source. However, relatively high volumes are still required to effectively collect these emissions in the manner. Although Local Hoods are more efficient than Canopies, they are undesirable from the maintenance and operating point of view.

The alternative of collecting Fugitive Emissions by means of a Furnace Enclosure appears to be the most practical solution since it allows collection of emissions at the source and prevents their escape into the atmosphere. With properly designed Furnace Enclosures, it is possible to effectively control Scrap Charging, Hot Metal Charging, Furnace Tapping, Ladle Alloy Additions, Furnace Slagging and Puffing Emissions with low volumes. At the present time, systems of this type are doing an effective job of Fugitive Emission Control with volumes of approximately 350,000 ACFM - 400,000 ACFM.

Figure 2 shows a typical schematic arrangement and design for the BOF Furnace Enclosure where the enclosure essentially forms a gas tight seal when the bi-parting doors are closed. Since the Furnace Enclosure extends below the charging floor, the only openings are for the ladle car. However, these openings can be effectively reduced by the addition of a vertical shield on the end of the ladle car, which will also increase the efficiency of the Furnace Enclosure.

Design of the Furnace Enclosure is based on sound engineering principles and actual testing, taking into consideration the volume of fumes generated inside the furnace due to the reaction of pouring hot metal into the furnace, as well as the velocity and temperature of the fumes leaving the mouth of the furnace.

Since the furnace is charged at a known angle, it is possible to calculate the horizontal and vertical components of the evolved emissions, as shown in Figure 3 and determine the necessary volumes and velocities required to contain these emissions inside the enclosure and prevent their escape into the atmosphere.

Enclosures of this type were developed initially to control emissions from the Q-BOP Process. However, the original enclosure designs have been modified to effectively collect the Charging, Tapping and Slagging Emissions generated during the Oxygen Steelmaking Process, in addition to Puffing Emissions during the Oxygen Blowing Period.

Original enclosure designs did not include a capability for Charging Emission Control, since a secondary hood was not included. To correct this situation, a secondary hood outside of the enclosure was added for collecting Charging Emissions. However, this proved to be inefficient due to the location of the secondary hood and insufficient volume for efficient fume collection. Today's improved design incorporates the secondary hood inside the Furnace Enclosure with sufficient volume for efficient charging emission control.

For controlling emissions during the blow and tapping period, the enclosure doors are closed, essentially forming a gas tight enclosure while the fumes are evacuated from the enclosure through the main or secondary hood. Figure 4 shows the effective collection of tapping emissions at this time. During the charging, the bi-parting doors are opened while charging scrap or pouring hot metal and the fumes are collected through the secondary hood located inside the enclosure directly above the furnace mouth.

With a properly designed Furnace Enclosure, it is possible to collect secondary emissions from the Basic Oxygen Process with approximately 90% efficiency, provided the charging of hot metal into the furnace is done at a controlled rate and the scrap is relatively clean.

One of the most recent BOF installations with effective Fugitive Emission Control Facilities (Figure 5) incorporates individual Furnace Enclosures over two (2) 350 metric ton vessels. The main Gas Cleaning Systems, consisting of two (2) Baumco Suppressed Combustion Systems rated at 295,000 ACFM at 164°F, are also utilized for secondary emission control and at the present time appear to be doing an effective job in controlling the Fugitive Emissions associated with the BOF vessel itself (Figure 6).

The total system here has been designed to insure that sufficient capacity is available at the secondary hood for Fugitive Emission Control when required.

Practically all new BOF/Q-BOP vessels that have been installed in the U.S. in the past two (2) years have included a partial or full Furnace Enclosure for Fugitive Emission Control. At the present time, there are five (5) operating BOF/Q-BOP Shops utilizing the Furnace Enclosure for Fugitive Emission Control with three (3) additional shops under construction. At the same time, Furnace Enclosures are being installed in operating BOF Shops without interrupting normal melting operations. Since the original enclosure designs had many deficiencies, these systems are operating today with varying degrees of success. Present enclosure design incorporates a secondary hood inside the Furnace Enclosure with sufficient volume for Fugitive Emission Control, capable of effectively collecting the Oxygen Steelmaking Fugitive Emissions under controlled conditions.

HOT METAL RELADLING

Hot Metal Reladling is another primary source of Fugitive Emissions in the Oxygen Steelmaking Process. The fumes generated at this time consist of 55% Iron Oxide less than 3 microns, 42% Graphite greater than 75 microns and 3% others with an approximate emission rate of 0.25 lbs per ton of hot metal. With today's technology, collection of reladling emissions is not a problem since it is possible to utilize a variety of canopy or local hoods in addition to close fitting ladle hoods depending on the arrangement of the reladling facility.

The main factor affecting the collection of reladling emissions is the distance of the hood from the ladle mouth as well as the rate of pouring hot metal. In actual practice, since the handling time remains almost constant regardless of the amount of hot metal handled, the volume required to control reladling emissions with a canopy or local hood is proportional to the volume of hot metal.

In contrast, utilization of a close fitting refractory lined ladle hood for collecting the reladling emissions allows fume collection at the source. The close fitting refractory lined ladle hood shown in Figure 8 utilizes the "air seal" principle where the fumes are drawn through a pouring slot in the hood and the gap between the hood and the ladle with sufficient velocity to prevent fumes from escaping into the atmosphere. Figure 9 shows a reladling fume control system with the hot metal poured through a slot on top of the ladle hood.

Actual efficiency of the ladle hood is demonstrated by the installation shown in Figure 10 where the reladling emissions for a 350 metric ton furnace are effecively collected with 125,000 ACFM. In this design, the hot metal is poured through a vertical slot in the movable ladle hood which serves two (2) reladling stations. The Gas Cleaning here is accomplished by a Baumco High Energy Scrubber which is also utilized for desulphurization emission control. In contrast, it is estimated that canopy or local hoods would require volumes in excess of 300,000 ACFM to effectively collect these emissions.

FLUX HANDLING

Flux Handling also contributes to the total Fugitive Emissions in the BOF Shop, but these emissions are minor in nature and easily controlled. The most common solution to this problem is to enclose the belt conveyors in the monitors with exhaust ducts placed at intervals along the belt and at each transfer point. A nominal volume of 500 - 600 CFM per foot of belt width should be adequate to effectively collect the fumes generated during Flux Handling. The fumes can then be exhausted to a small package Baghouse or tied into an existing Gas Cleaning Source.

ELECTRIC ARC FURNACE - CHARGING & TAPPING EMISSION CONTROL

Development of the Electric Arc Melting Process over the years has resulted in larger furnaces and increased emissions from the furnace. With today's requirements for controlling all emissions and the necessity for large volumes to collect the scrap charging and tapping emissions, the Dry Bag Filter ("Baghouse") is primarily used for this application. This allows the same system to be used for primary emission control as well as secondary emission control.

In the past there has been little success in collecting these emissions. However, recent developments in collecting Electric Arc Furnace charging and tapping emissions include enclosing the furnace aisle area, making it possible to contain the fumes in the enclosed furnace aisle allowing the Fugitive Emissions to be collected with smaller gas volumes than with the conventional overhead canopy hood method.

Figure 10 shows an arrangement in which the furnace is installed in a fully enclosed furnace aisle with one overhead crane traveling inside for scrap charging and a transfer car with ladle for tapping. The only openings in the enclosure are at yard elevation for the ladle and scrap bucket transfer cars.

Recent developments include total enclosure of the arc furnace as shown in Figure 11 in order to contain the charging fumes, allowing their collection with a minimum volume. This also provides for sound control by insulating the enclosure. In this case, tapping fumes are collected in a close fitting hood, using a common gas cleaning system for both charging and tapping emission control. The method makes direct evacuation or side draft hoods for melting emission control unnecessary.

CONCLUSION

Technology for Fugitive Emission Control has lagged behind the technology developed for main Gas Cleaning Systems in the Iron and Steel Industry because the Fugitive Emissions were considered minor in comparison to the emissions generated during the actual melting periods, and the fact that Regulatory Authorities were willing to tolerate these emissions while concentrating on other more important areas. As a result, at the present time, system applications for Fugitive Emission Control have not reached the same degree of reliability.

This gap in technology is gradually closing due to current pressure by the Regulatory Authorities to control all Fugitive Emissions. This is evidenced by the evolution of the total Furnace Enclosure for Oxygen Steelmaking and Electric Arc Furnaces, and development of the close fitting ladle hood for controlling reladling emissions, both of which are capable of effectively controlling Fugitive Emissions with minimum volumes and cost.

Little has been done in the U.S. to develop new technology for Blast Furnace Cast House Emission Control. However, we can expect more activity in this area as the Regulatory Authorities increase pressure for total control of Blast Furnace Emissions.

Fugitive Emission Control that will be acceptable to the Iron and Steel Industry requires a technology that offers the most effective and economical type of Fugitive Emission Control from the standpoint of working environment which will allow these emissions to be collected at their source and prevent their escape into the atmosphere.

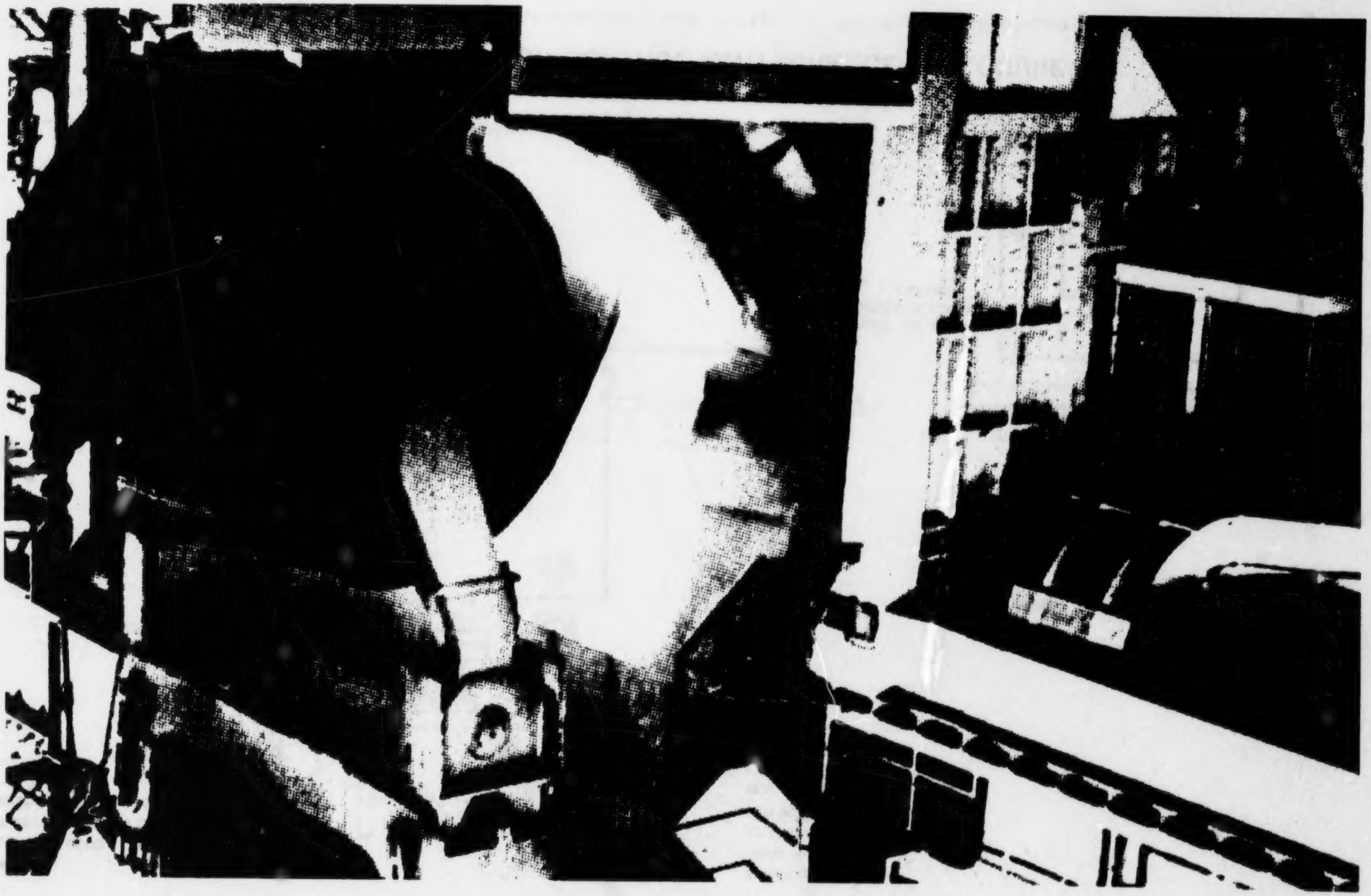
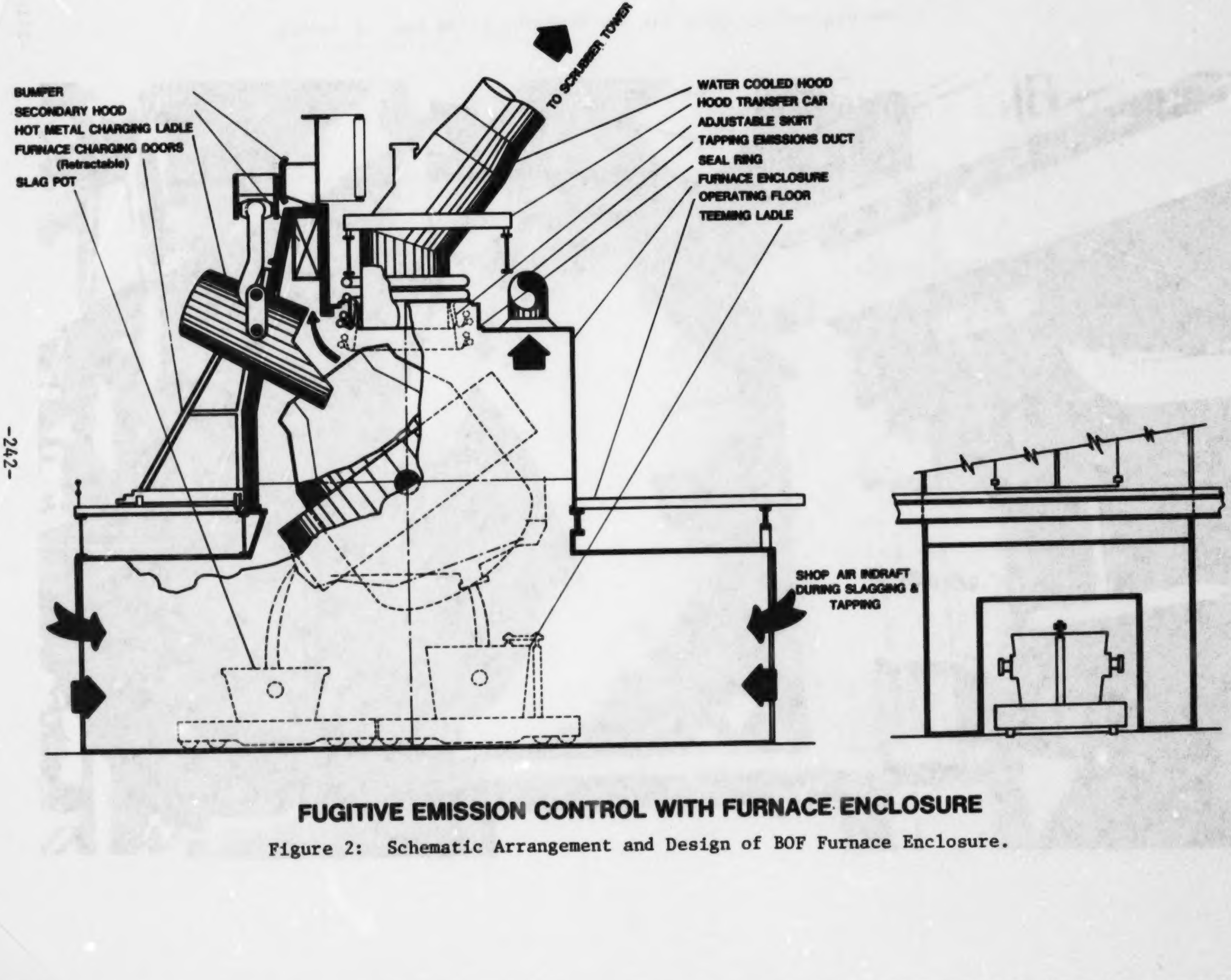


Figure 1: Hot Metal Charging for the Basic Oxygen Process.



TO SCRUBBER TOWER
BUMPER
SECONDARY HOOD
HOT METAL CHARGING LADLE
FURNACE CHARGING DOORS (Retractable)
SLAG POT
WATER COOLED HOOD
HOOD TRANSFER CAR
ADJUSTABLE SKIRT
TAPPING EMISSIONS DUCT
SEAL RING
FURNACE ENCLOSURE
OPERATING FLOOR
TEEMING LADLE
SHOP AIR INDRAFT DURING SLAGGING & TAPPING

FUGITIVE EMISSION CONTROL WITH FURNACE ENCLOSURE

Figure 2: Schematic Arrangement and Design of BOF Furnace Enclosure.

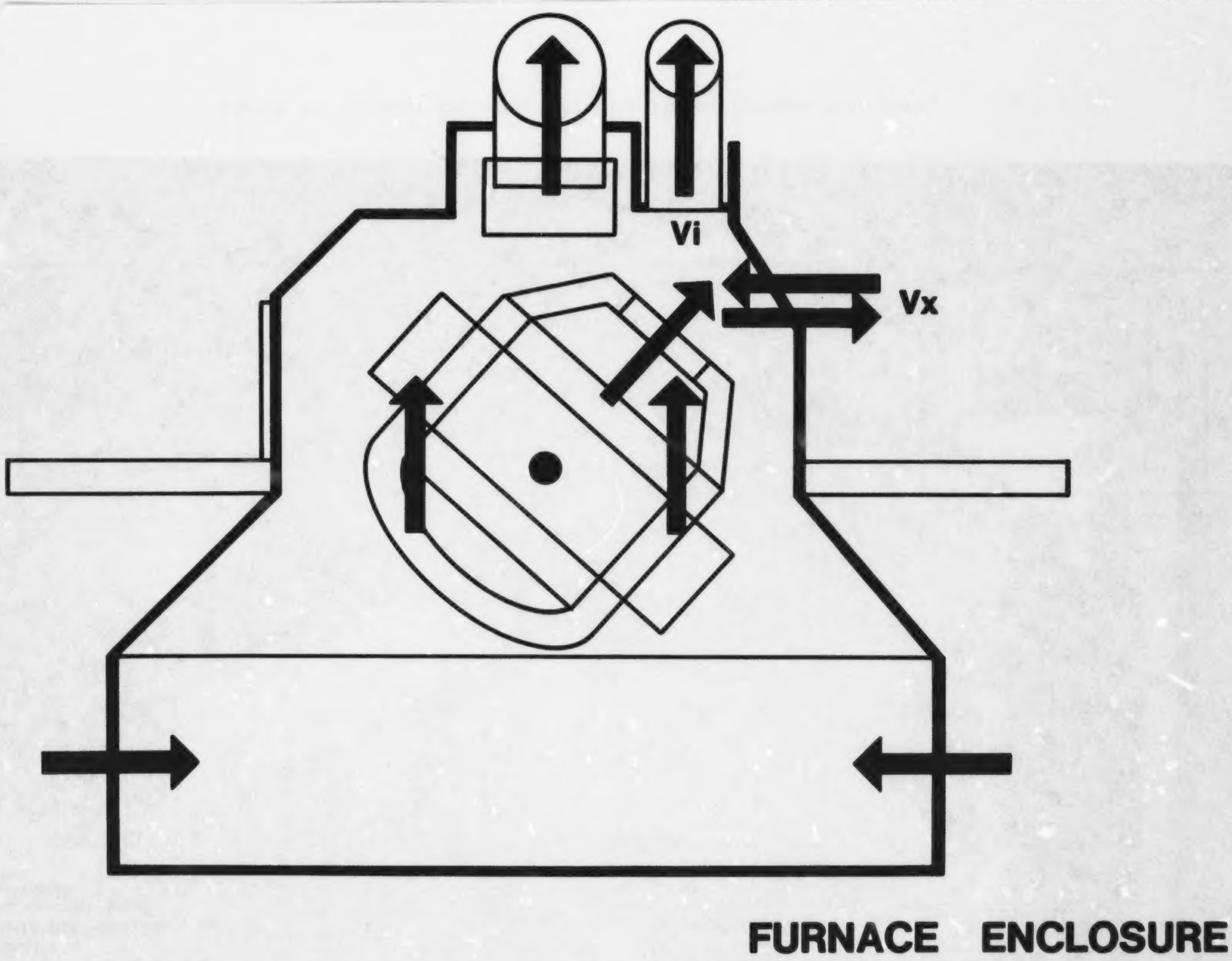

Vi
Vx
FURNACE ENCLOSURE

Figure 3: Schematic Arrangement Showing Components Effecting Fugitive Emission Control with Furnace Enclosure.

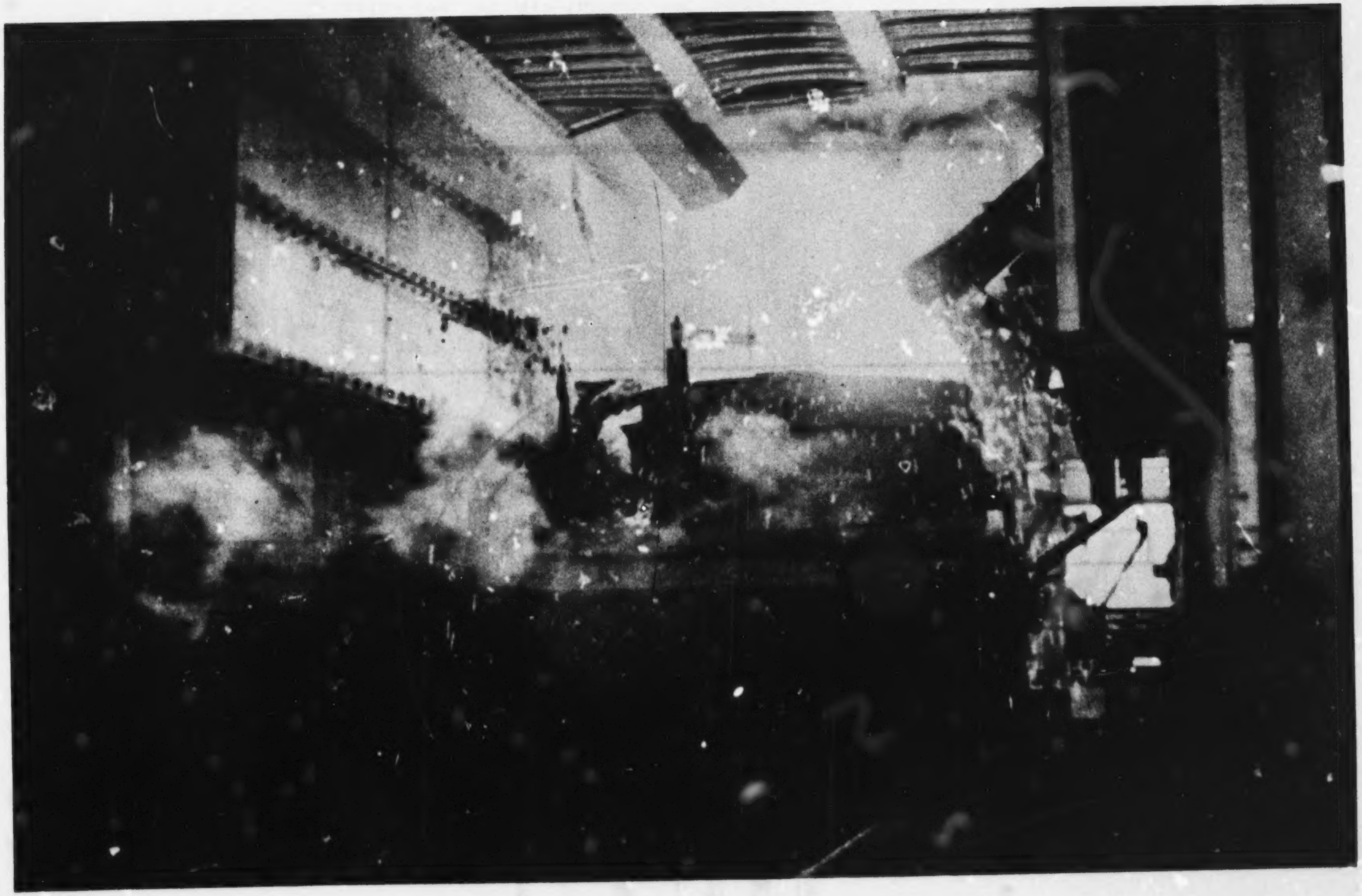


Figure 4: Tapping Emission Control with BOF Furnace Enclosure.

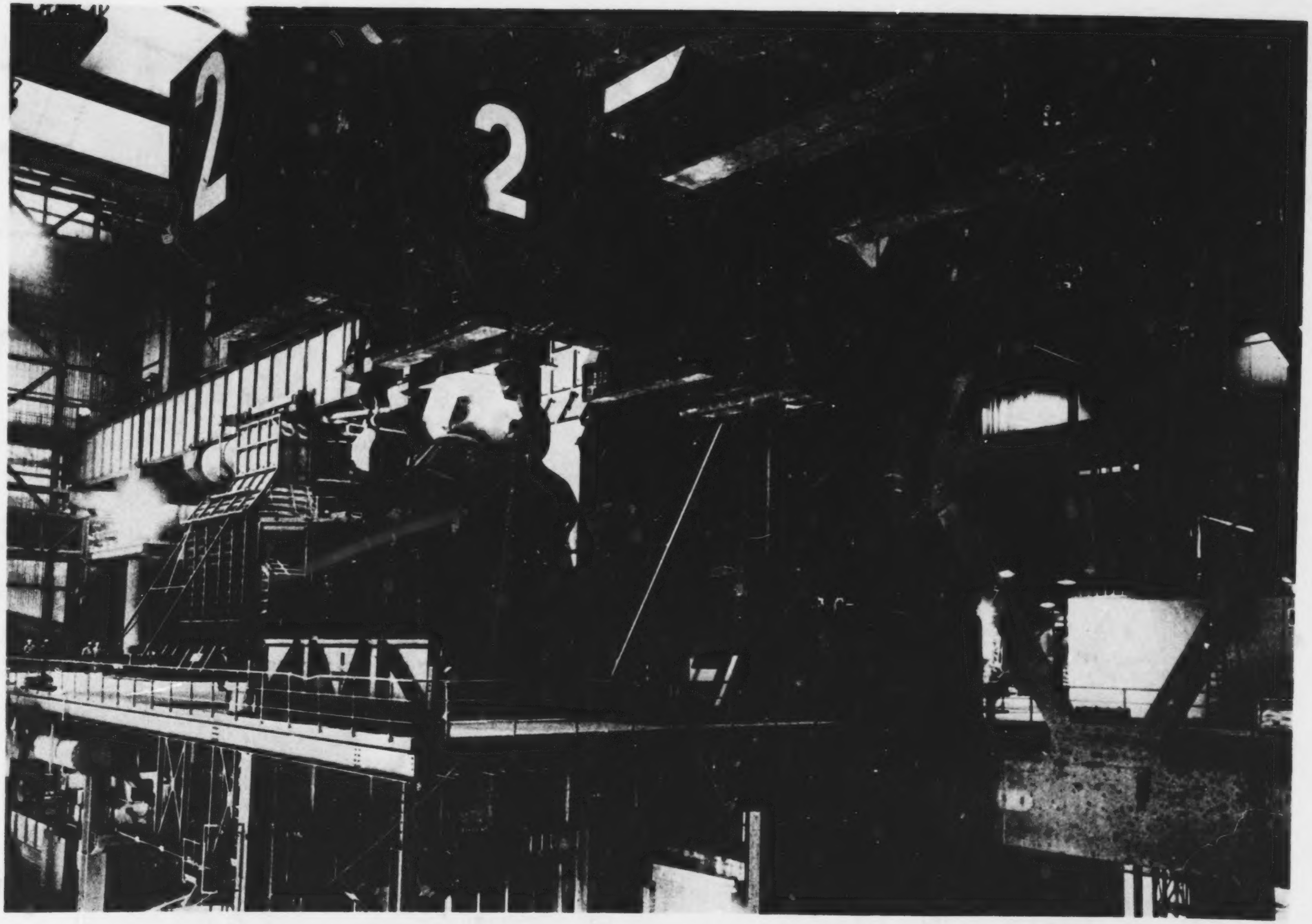


Figure 5: Recent BOF Shop Installation with Fugitive Emission Control.

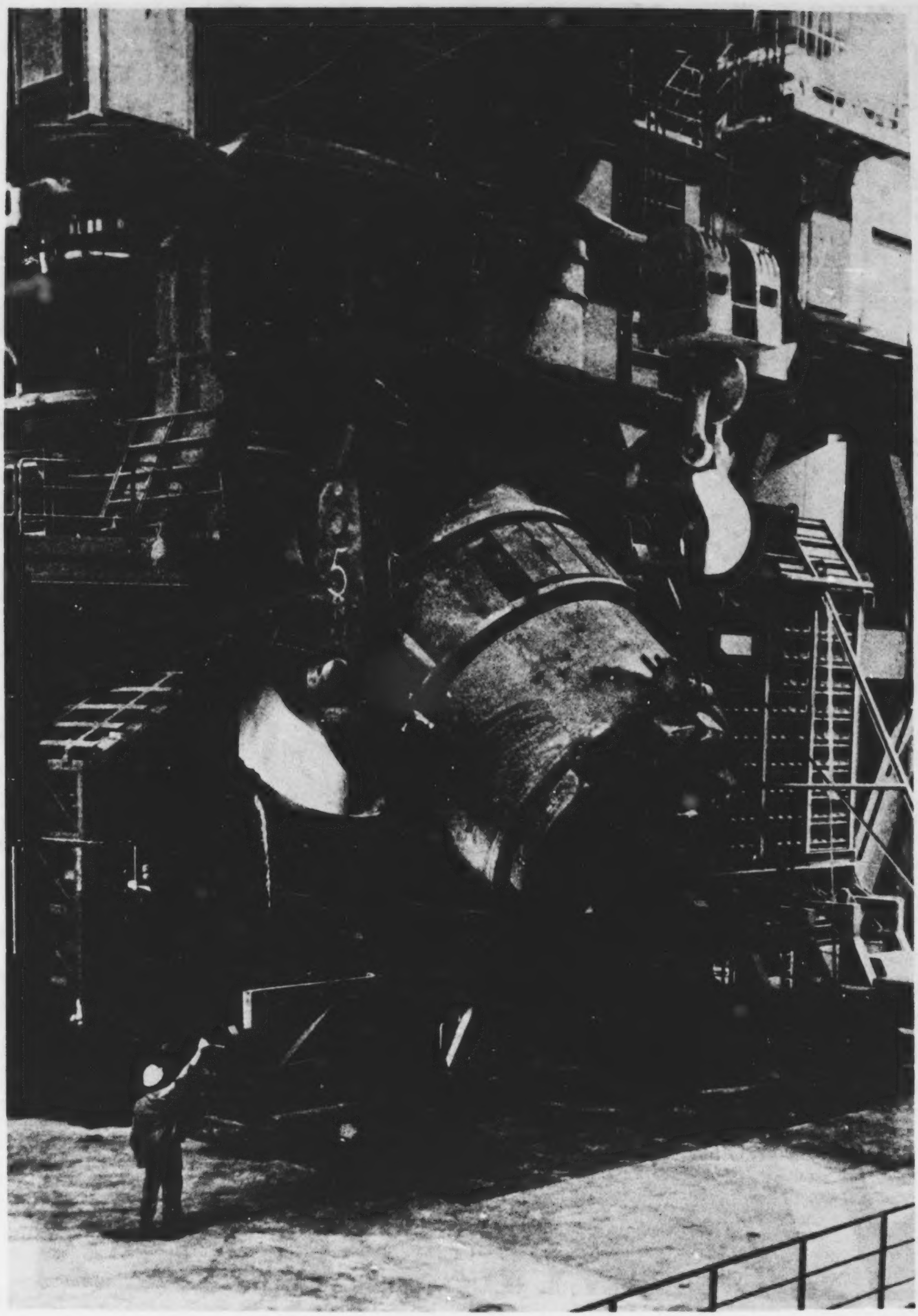


Figure 6: Hot Metal Charging Emission Control with Furnace Enclosure.

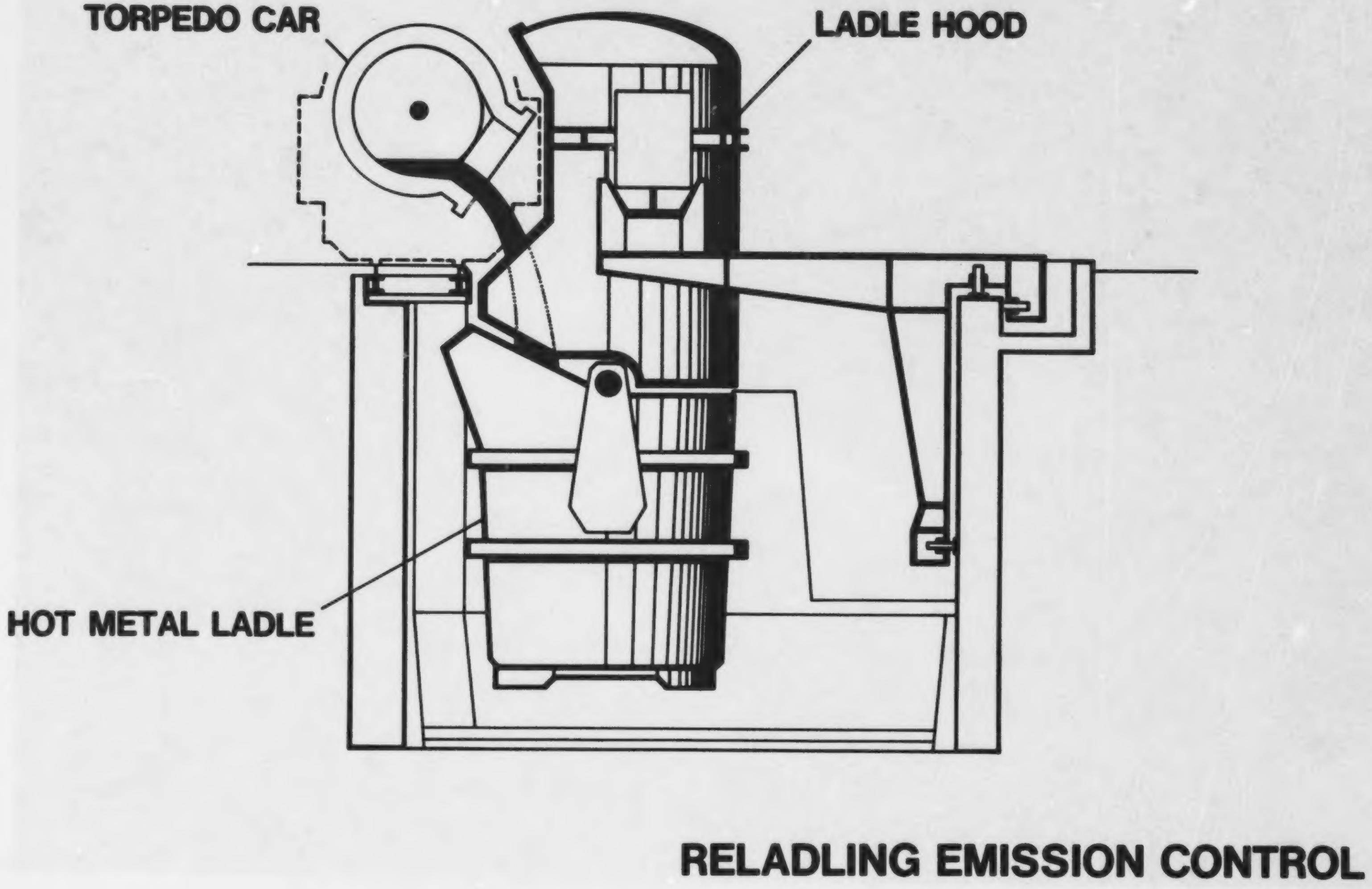

TORPEDO CAR
LADLE HOOD
HOT METAL LADLE
RELADLING EMISSION CONTROL

Figure 7: Schematic Arrangement - Ladle Hood for Reladling Emission Control.

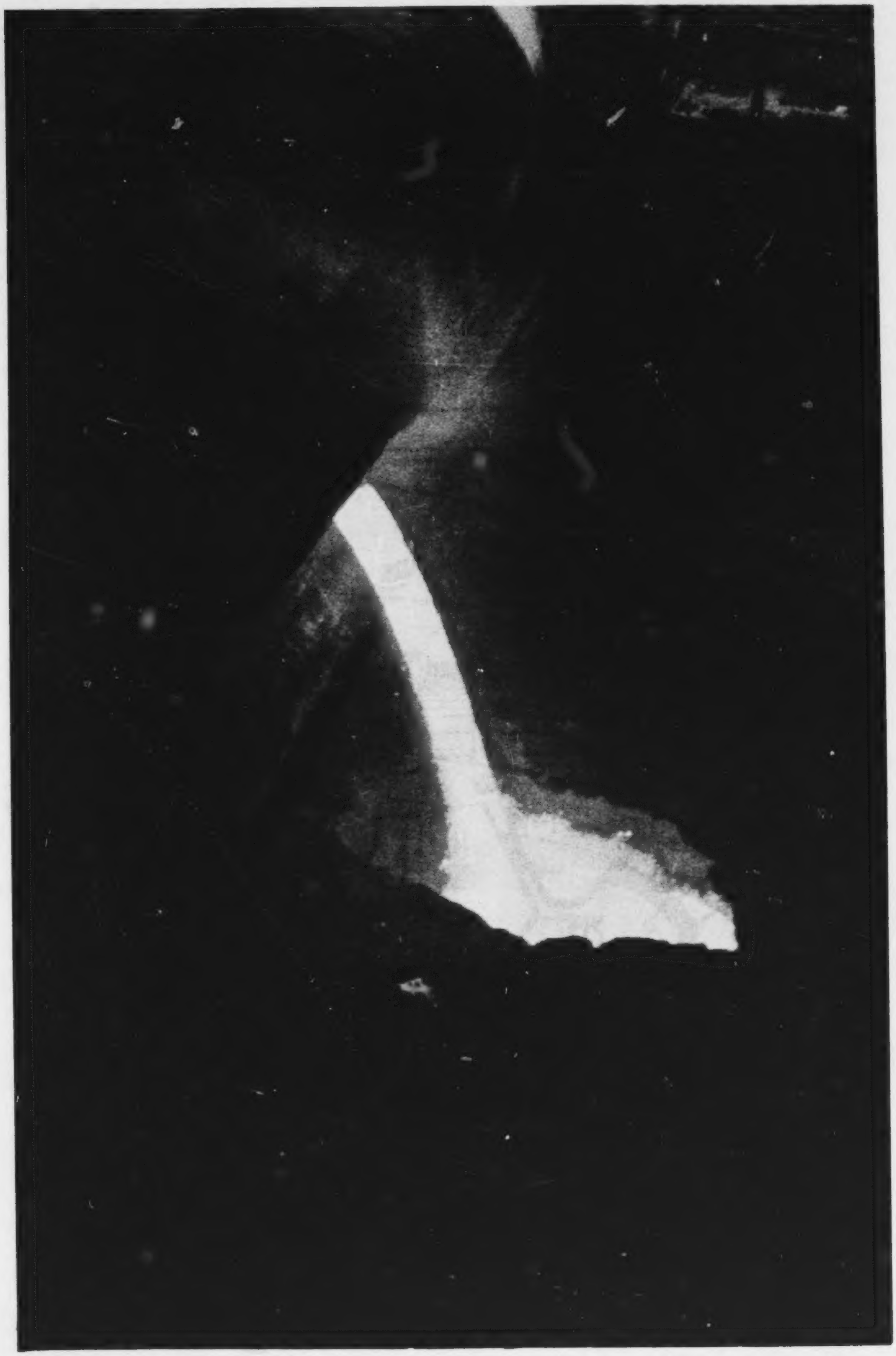


Figure 8: Reladling Emission Control - Pouring through a Slot on Top of the Ladle Hood.

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best available copy.

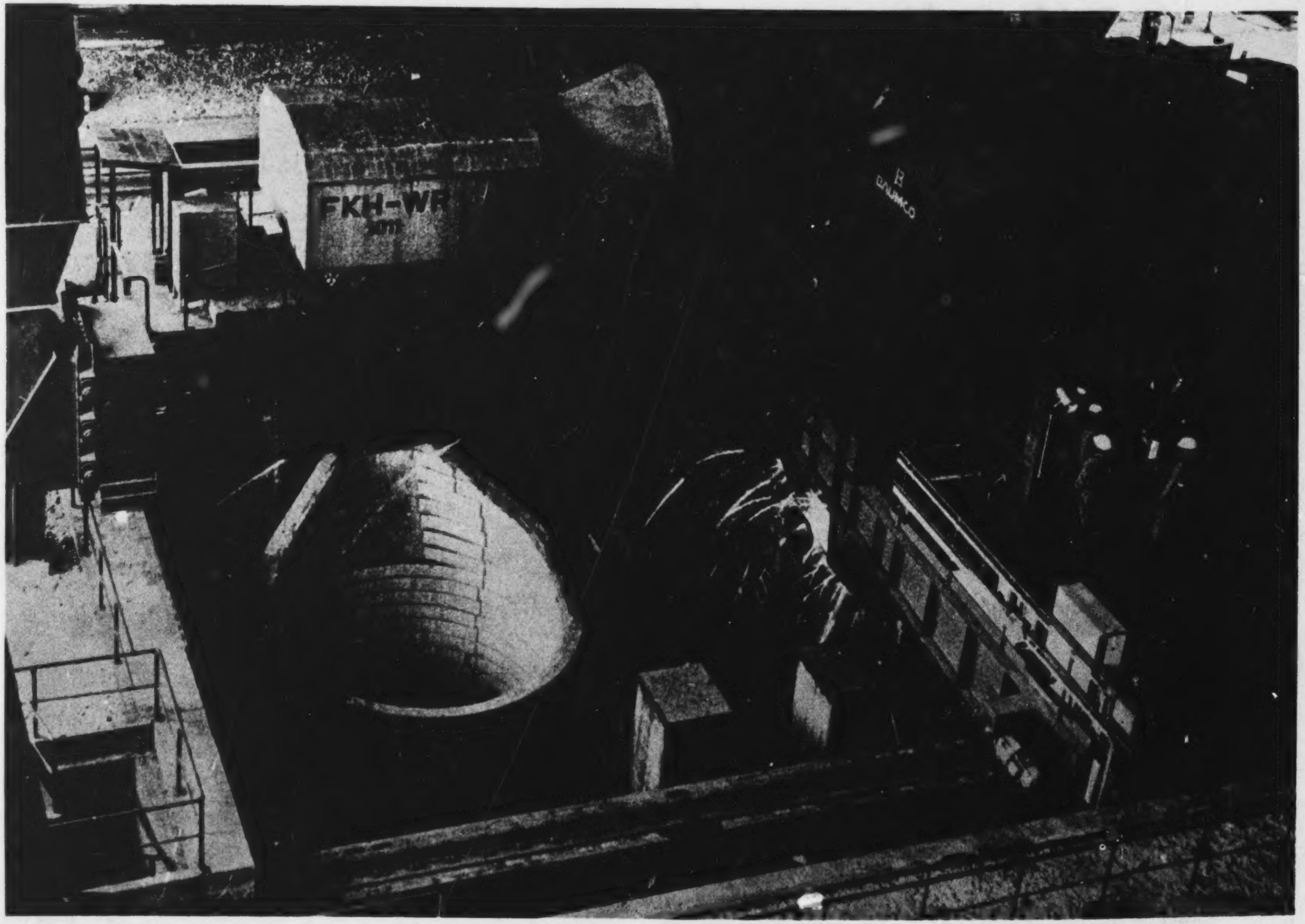

Figure 9: Reladling Emission Control - Pouring through a Vertical Slot in the Ladle Hood.

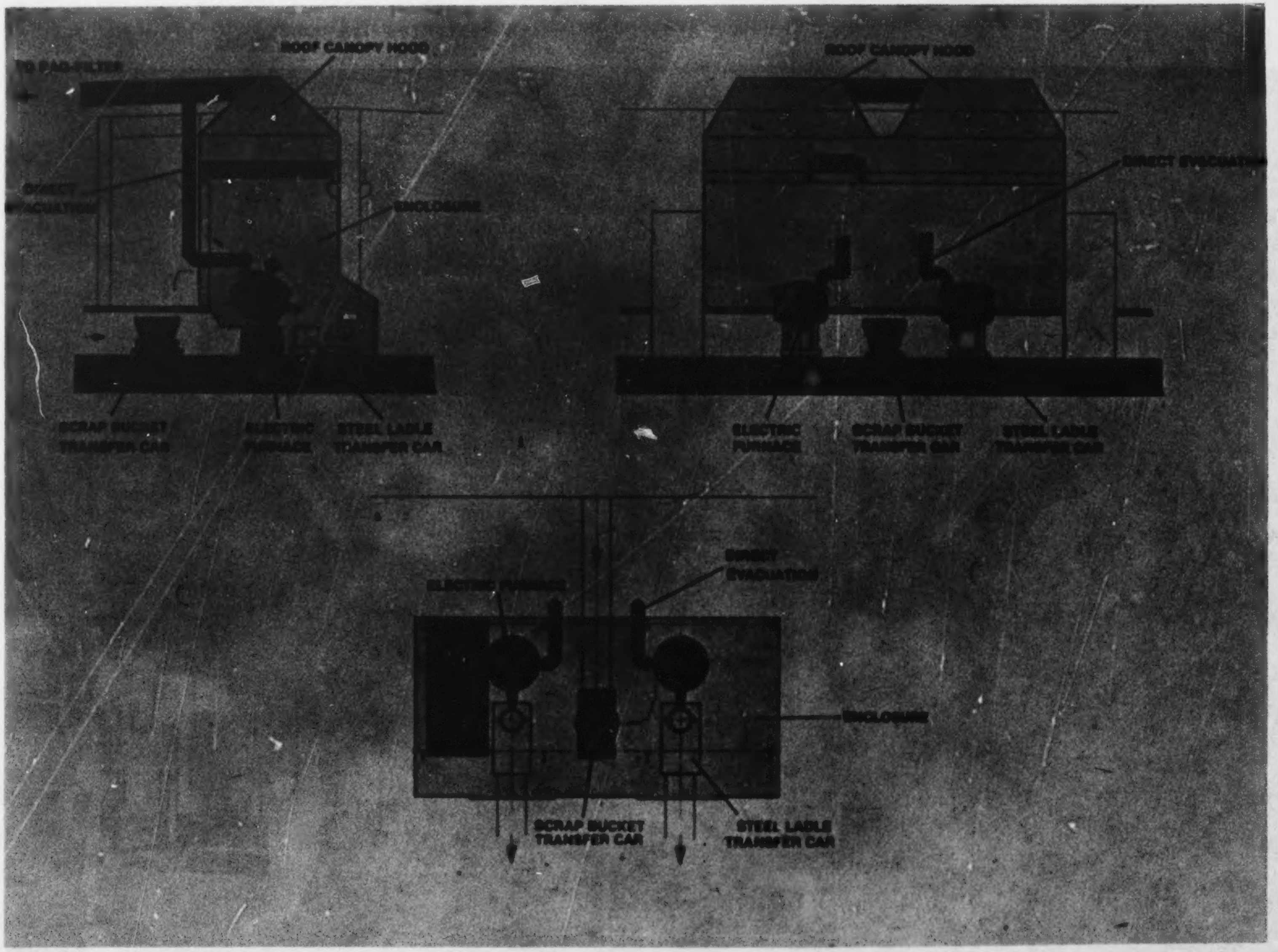
TO BAG-FILTER
ROOF CANOPY HOOD
DIRECT EVACUATION
ENCLOSURE
SCRAP BUCKET TRANSFER CAR
ELECTRIC FURNACE
STEEL LADLE TRANSFER CAR
ROOF CANOPY HOOD
DIRECT EVACUATION
ELECTRIC FURNACE
SCRAP BUCKET TRANSFER CAR
STEEL LADLE TRANSFER CAR
DIRECT EVACUATION
ELECTRIC FURNACE
ENCLOSURE
SCRAP BUCKET TRANSFER CAR
STEEL LADLE TRANSFER CAR

Figure 10: Schematic Arrangement - Electric Furnace Pollution Control System with Enclosed Furnace Aisle.

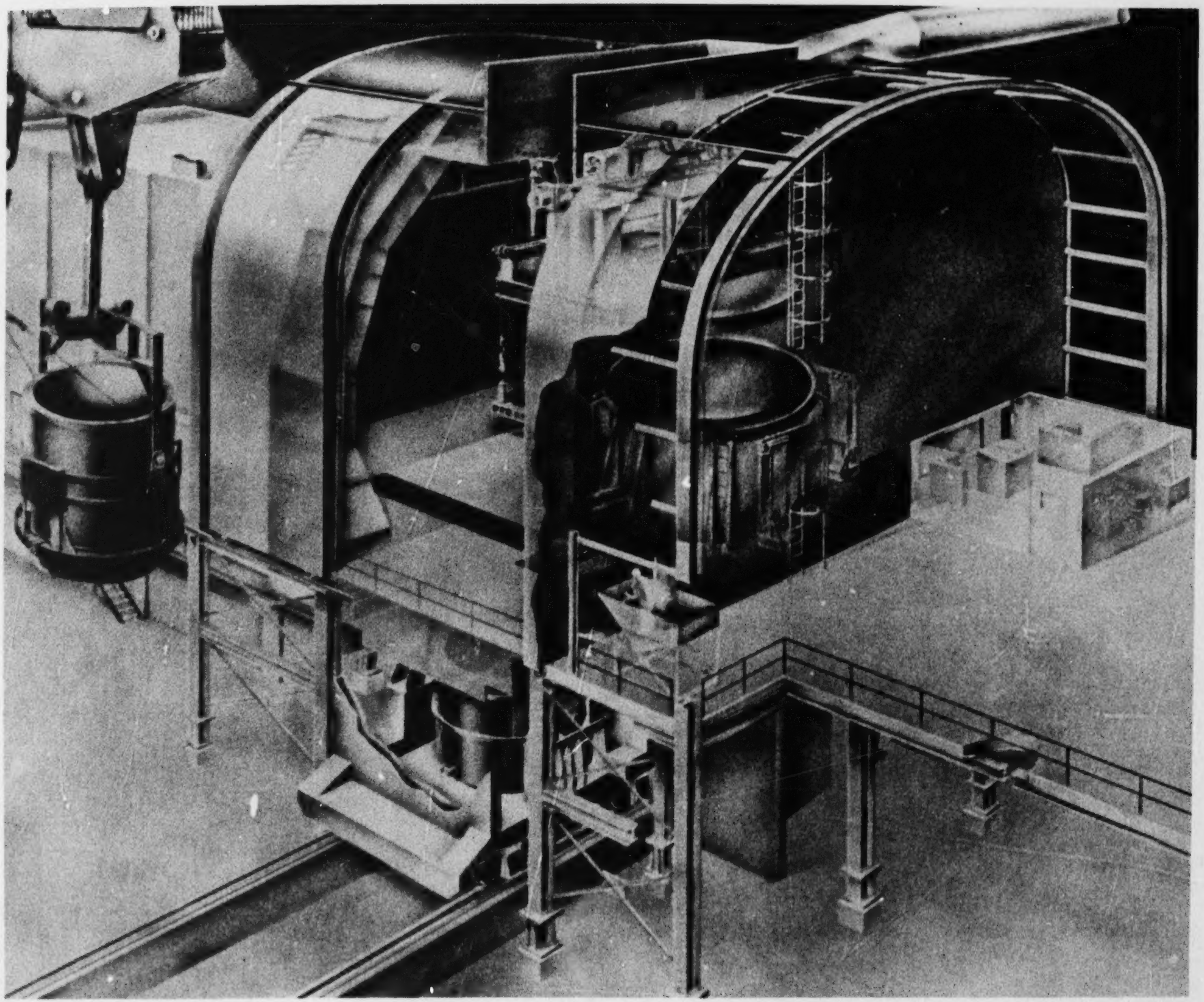

Figure 11: Furnace Enclosure for Emission Control on Electric Arc Furnace.

Tuesday Afternoon - May 24, 1977

SESSION IV: WATER

Chairman: Charles E. Billings, Ph.D., *Consultant*

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* indicates speaker

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STORMWATER: ONE STEEL MILL'S EVALUATION

By

John W. Luton, Associate Pollution Control Engineer

and

William B. Chadick, Senior Pollution Control Engineer

Armco Steel Corporation
Houston, Texas

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STORMWATER: ONE STEEL MILL'S EVALUATION

John W. Luton, Associate Pollution Control Engineer
William B. Chadick, Senior Pollution Control Engineer

Pursuant to effluent discharge permits, Armco Steel's Houston Works has conducted an extensive stormwater survey. This survey has proven to be the first report of its nature in the steel industry. The scope of the survey deals not only with quantity, but also quality of direct stormwater runoff.

Results of the survey tend to show that stormwater quality from the Houston Works is generally of an inert, particulate composition. Little evidence of a "first flush" effect or organic constituents was observed. Generally, in all cases of well defined flow hydrographs, the maximum constituent concentration corresponded to samples taken near peak flow rates. It was also determined that for certain ranges of storm events the average concentrations of runoff parameters was directly related to the total volume of runoff. This paper covers the methodology and results of the survey.

STORMWATER: ONE STEEL MILL'S EVALUATION

Armco Steel Corporation operates a fully integrated steel mill in Houston, Texas capable of producing approximately 1.8 million ingot tons of steel per year. As a completely integrated steel mill, the Houston Works starts with the raw materials of iron ore, coal and limestone and produces finished products of plate and structural shapes. All treated process wastewaters and stormwater discharge directly to the Houston Ship Channel. The Houston Ship Channel being a dredged channel which provides a deep water port to Houston, a city located fifty miles inland from the Gulf of Mexico.

Pursuant to effluent discharge permits, the Houston Works has undertaken an extensive stormwater survey. This survey has proven to be the first report of its nature in the steel industry. The scope of the survey deals not only with quantity, but also quality of direct stormwater runoff. The most significant aspects revealed by the survey are the absence of a "first flush" effect, the absence of significant quantities of organic matter, and the establishment of ratios of those organics to carbon based parameters (BOD_5/TOC).

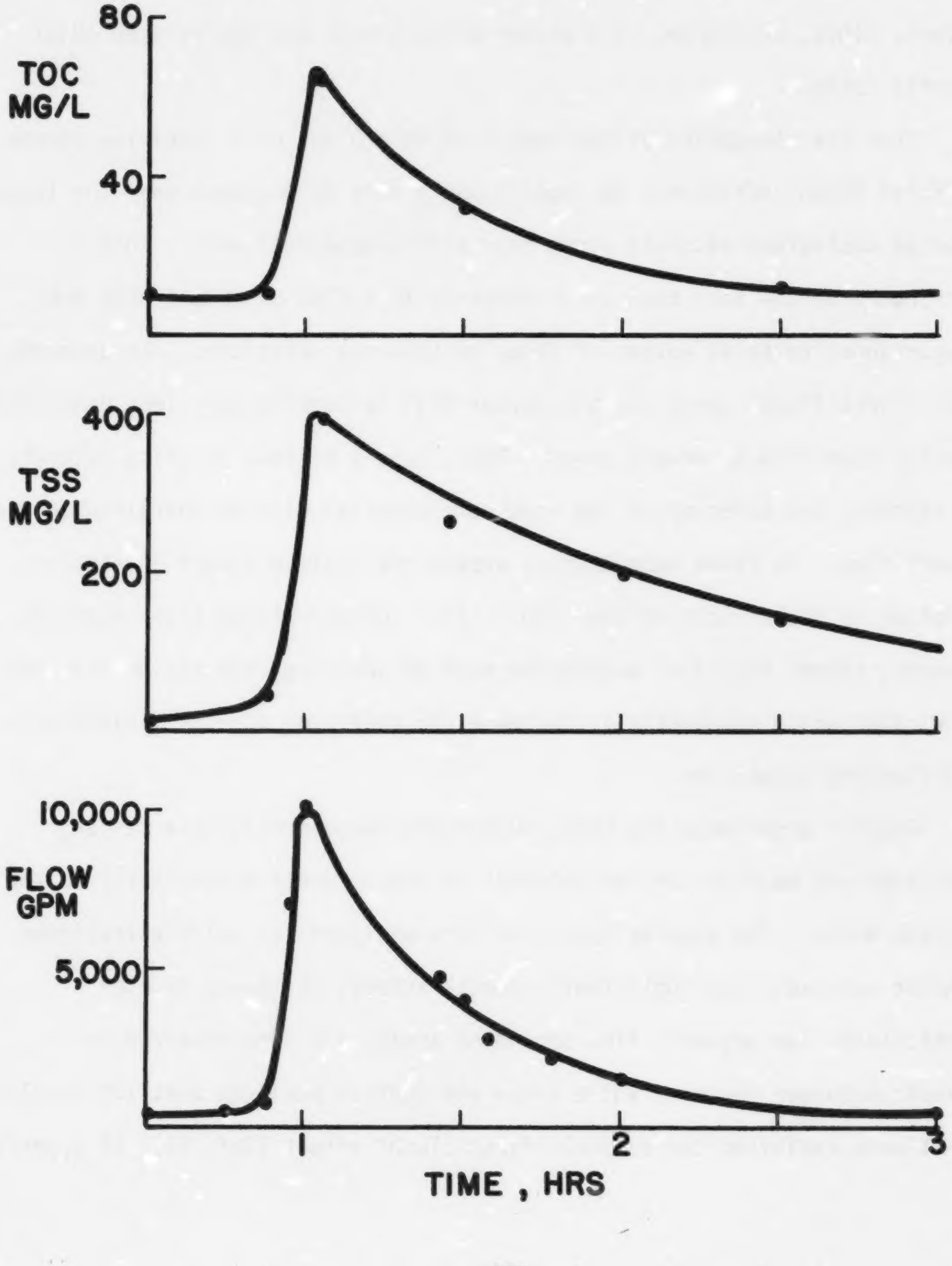
After completing a literature search, it was determined that a comprehensive stormwater survey had never been undertaken in the iron and steel industry. This fact was confirmed by engineers currently under contract to the United States Environmental Protection Agency (USEPA) now performing such a study nationwide (Ref. 1).

Armco undertook studies to determine drainage basin characteristics. This included size, shape and activity of each basin. Then, hydrographs of direct stormwater runoff were observed from one of the more typical basins. These hydrographs were typical with those experienced in the literature (Ref. 2). It was also determined that the runoff/rainfall ratios were within the range predicted by empirical coefficients (Ref. 3).

Discrete grab samples were then taken sequentially throughout a direct runoff event. These samples were analyzed for pH, Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Oil and Grease (O&G) and Total Organic Carbon (TOC). When concentrations of these parameters were plotted against time (paramographs), it was noted that the concentrations plotted in the general outline of the flow hydrograph. Figure 1 illustrates the hydrograph and TSS and TOC paramographs for a 0.39 inch rainfall with an effective duration of approximately fifteen minutes. This figure is representative of all but one of twenty-two events sampled. The range of intensities and durations of these events will be discussed later.

As seen in Figure 1, peak concentrations were found to align with the peak flows. The concentrations, more or less tracked the flow hydrograph outline. This has been termed a "flow dependent" effect as contrasted with the "first flush" effect prevalent in the literature. "First flush" is defined as: "The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow" (Ref. 4). This is significant both from the standpoint of design of stormwater treatment facilities and from the impact of the stormwater on a receiving water-

FIGURE I
TYPICAL HYDROGRAPH & PARAMOGRAPHS FOR STORM DISCHARGES



course. As the majority of pollutants in a "first flush" area occur before peak flows are encountered, treatment facilities in these areas would be considerably smaller than for the same basin exhibiting a flow dependent effect. This, of course, is a matter of economics and the related cost/benefit ratio.

From the standpoint of the impact of stormwater on a receiving stream, a "first flush" effect may be significantly more deleterious than the impact from an equivalent rainfall event from a flow dependent area. This is attributed to the fact that concentrations in a flow dependent area are proportional to total volume of flows or scouring velocities. It appears that "first flush" areas contain matter that is considerably less dense and smaller than flow dependent areas. Thus, once a minimum scouring velocity is reached, the majority of the scourable material will be entrained in the runoff flow. As flows increasingly exceed the minimum scouring velocity, dilution of the effects of the high initial concentrations also increases. However, storms that just exceed the minimum scouring velocity do not have flow rates which substantially increase the receiving streams assimilative and flushing capacities.

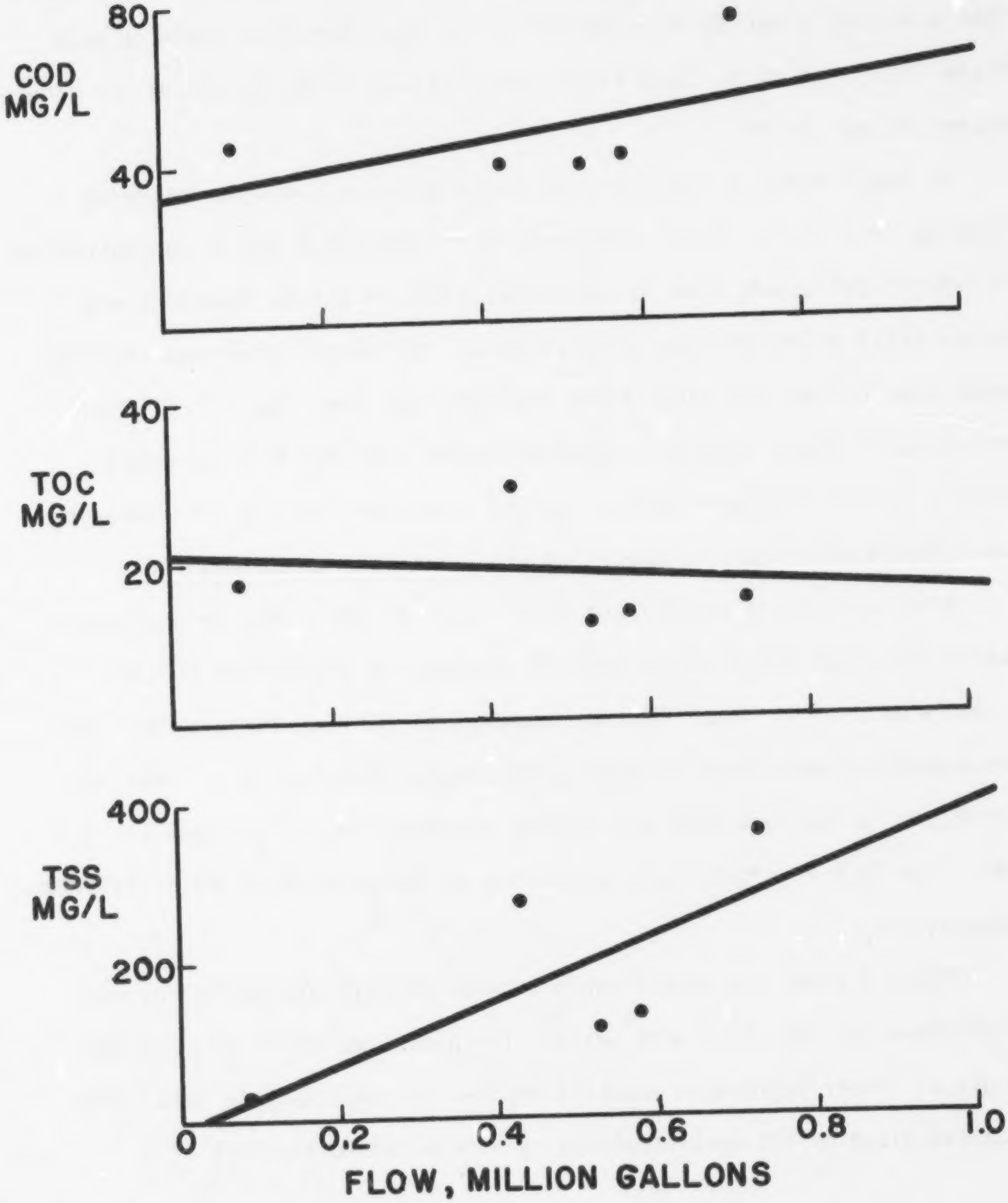
Armco's experience has shown relatively large particulate matter comprises the majority of "pollutants" in storm runoff discharges from the Houston Works. The samples that have been analyzed for soluble fractions exhibit extremely low "pollutant" concentrations. Evidence of high particulate, low organic, flow dependent areas have been observed in Atlanta suburban regions, while urban and central business district samples in Atlanta exhibited the typical "first flush" effect (Ref. 5). It appears that the flow dependent areas of suburban Atlanta and the steel mill in Houston contain relatively inert particulates. These particulates are scoured in proportion to flow. No correlation is available, but it appears that a minimum scouring velocity for a flow dependent area would be much higher than that of a "first flush" area because of the nature of the scoured matter in each basin.

A runoff event of the magnitude which produces a minimum scouring velocity in a "first flush" area would contribute much higher concentrations of organic pollutants than an equivalent event in a flow dependent area. As the total volume of flow would be equal, the assimilative and flushing capacities in the receiving stream would be the same. The "first flush" effect would impart more of a negative impact than the flow dependent effect. A flow dependent effect has the redeeming features of increasing assimilative and flushing capacities with increased pollutantal load.

Armco also found significant statistical evidence that in the larger basins (60.5 and 142.8 acres) studied, average concentrations varied linearly with total flow. This was determined for TSS, TOC and COD. O&G concentrations were found to exhibit no concentration pattern. This was attributed to the fact that the highest concentration of O&G seen was 2.0 mg/l. The lack of significant quantities of O&G prohibited any statistical correlations.

Figure 2 shows the relationship between average concentrations and total flows for the 142.8 acre basin. The plots, as exhibited, are the result of linear regression analysis applied to the available data. The negative slope of TOC concentrations is attributed to the lack of

FIGURE 2
AVERAGE CONCENTRATIONS VERSUS TOTAL DISCHARGE
142.8 ACRE BASIN



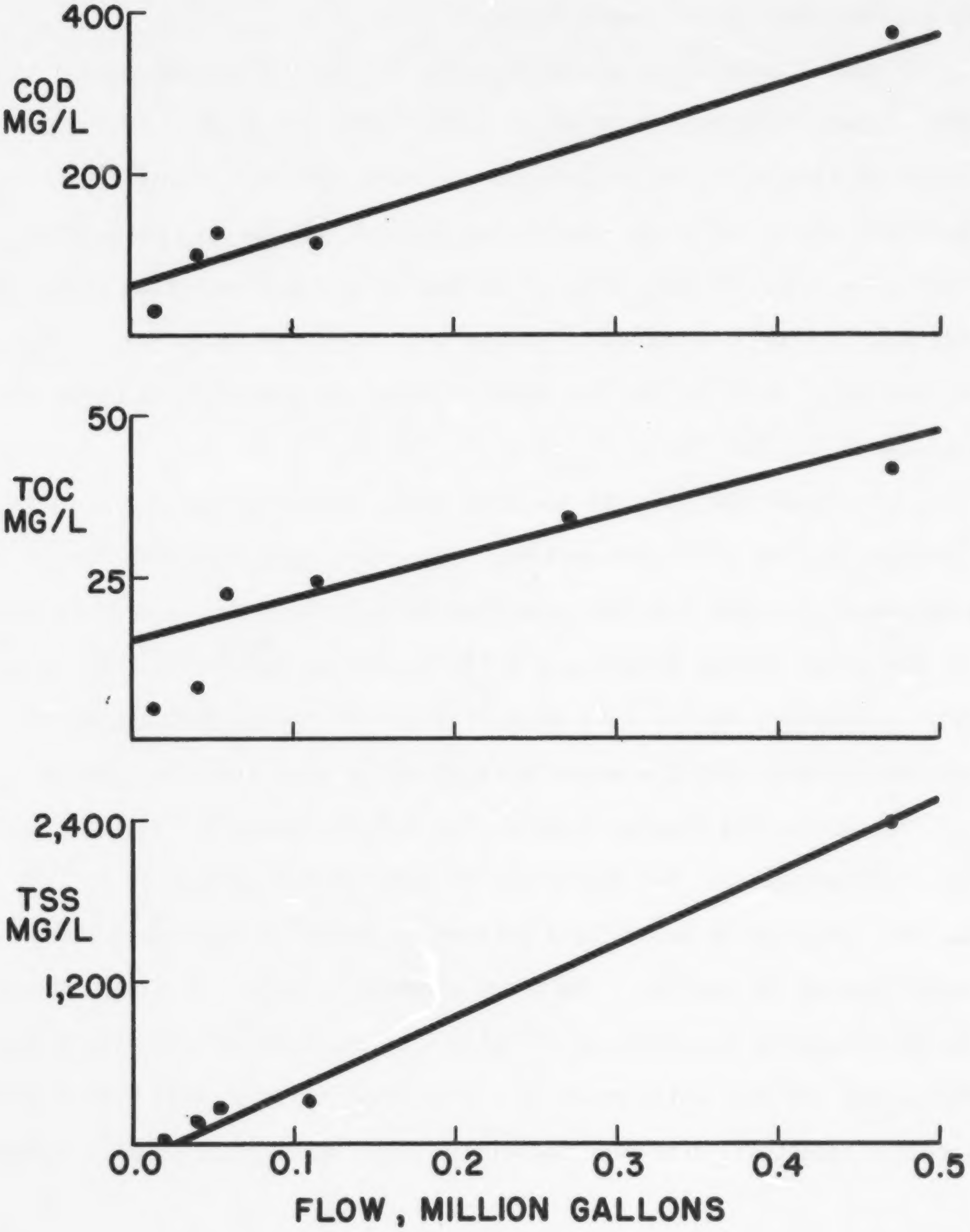
appreciable quantities of organic material in the basin. This is confirmed by two sets of BOD_5 samples which averaged less than 4 mg/l. It is assumed that this limited quantity of scourable organic material is in fact diluted by increasingly larger runoff events.

Figure 3 shows plots of average TSS, TOC and COD concentrations versus total flows in the 60.5 acre basin. These plots are similar to those discussed in Figure 2. The projections represent the best linear fit for all the given data. While the given lines for TSS and COD have correlation coefficients greater than 99%, if the data from the lowest flow event were removed, the correlation would be even more statistically precise. For the TOC relation, removing the low point provides an increase from under 95% to between 95% and 99%.

It is theorized that the low flow event did not exceed the minimum scouring velocity discussed earlier. Therefore, concentrations from this event would be lower than the predicted values, which can be seen in Figure 3. While the minimum scouring velocity is professed, there is not enough data available to define its limits. It is anticipated that a specific minimum scouring velocity would be required for each individual basin.

The plots from Figures 2 and 3 also indicate the site specificity of data between basins. The two basins in question are similar in activity, but the larger basin has a field determined rainfall/runoff coefficient twice that of the smaller. The three parameters shown vary widely between basins. Based on the Armco and Atlanta studies, transfer of data between basins may not be a valid practice. This data indicates that even within a specific industrial area each individual basin may exhibit totally different

FIGURE 3
AVERAGE CONCENTRATIONS VERSUS TOTAL DISCHARGE
60.5 ACRE BASIN



stormwater quality characteristics.

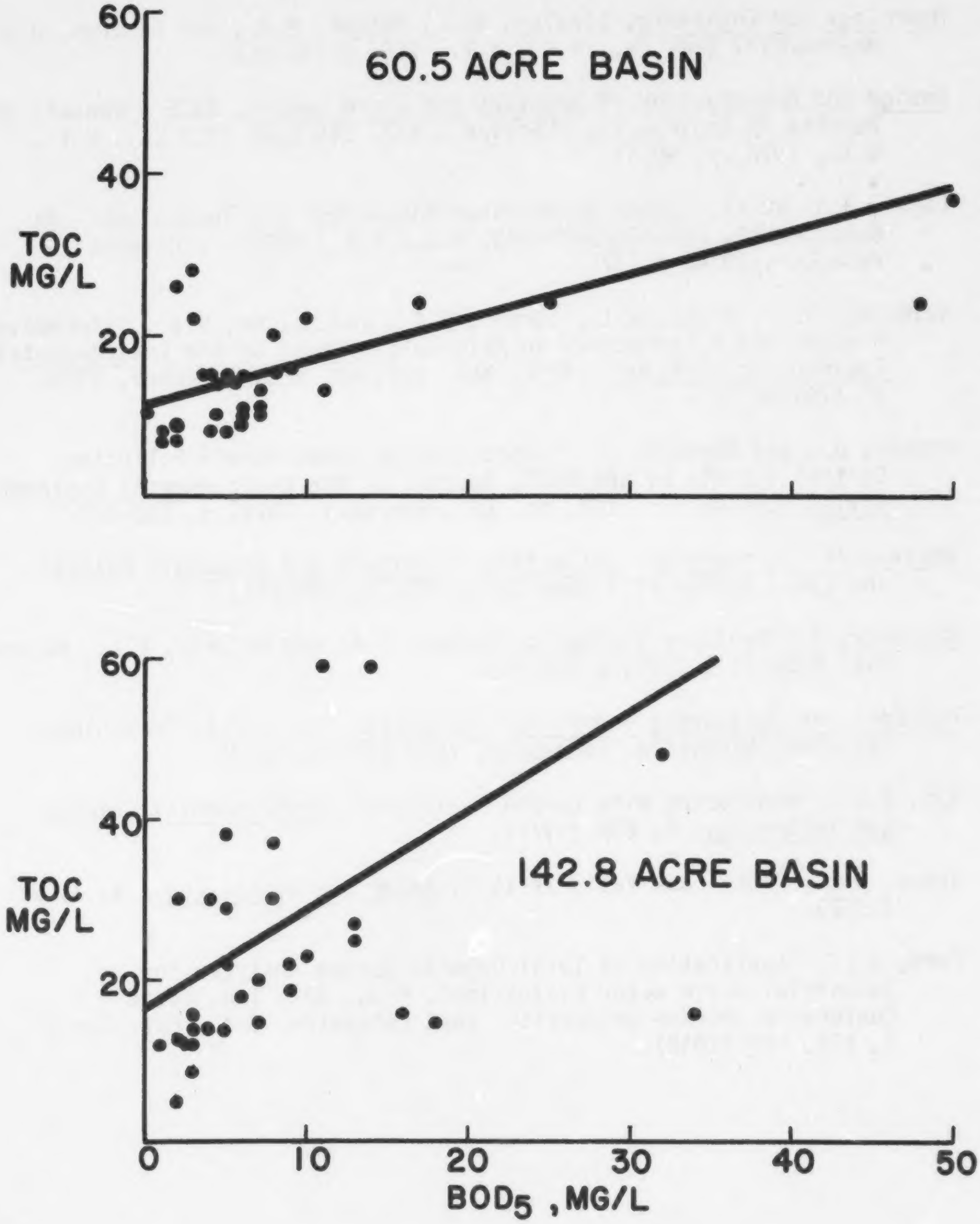
While no attempts were made to correlate the effects of the number of antecedent dry days preceding each sampled event, the general findings are interesting. Lager (Ref. 3) states that "higher concentrations of pollutants are generally expected after prolonged dry periods". Kuhner and Shapiro (Ref. 6) question whether this accumulation of material is linear or after a long enough time frame a leveling off occurs. From the data at the 142.8 acre basin, there was only one event that was preceded by more than two dry days. For TSS and TOC concentrations the actual value was almost twice the expected value. There was slightly more variation in the number of preceding antecedent dry days in the 60.5 acre basin. In general, those events preceded by more than two dry days exhibited higher concentrations than the predicted values. The available data is sufficient to provide general quality relationships to flow. However, more data is required in order to expand those relationships to include any effect of antecedent dry days.

BOD_5 is the parameter most widely used in the evaluation of non-process wastewater effect on the oxygen level in a receiving stream. BOD_5 is not without faults; and has been criticized for its lack of reproducibility, the time required for analysis, the necessity of seed acclimation and the fact that a BOD_5 represents one point on a rate curve (Ref. 7, 8, 9, 10). TOC, on the other hand, is a very rapid, accurate measurement of which no organic chemicals have been found that are resistent to the nature of the procedure. If TOC is to be utilized as a parameter for waste characterization and water quality monitoring, it must be correlated to the specific oxygen based parameter to be replaced, COD or BOD_5 (Ref. 11). However, there is no available correlations of TOC/BOD_5 for stormwaters.

Armco has attempted this correlation for the 60.5 and 142.8 acre basins. The data available is shown in Figure 4. Both linear projections represent lines with statistical reliability greater than 99%. As with the data previously discussed, there is considerable difference in the relationships between basins. Technology transfer would not be applicable in this case either. However, even if a TOC/BOD_5 relationship were developed, Ford (Ref. 12) warns that "TOC should not be considered a replacement for BOD_5 or COD, but rather an additional parameter for measuring organic pollution".

Armco feels it's efforts at characterizing stormwater quality at the Houston Works have been very educational. Presently, it is felt that rational attempts can be made at predicting the effects of a rainfall/runoff event at the Houston Works. However, it must be remembered that each rainfall/runoff event is a unique occurrence. The variables entailed are numerous; such as intensity, duration, antecedent dry days, and localized non-routine activities within a drainage basin. While process wastewaters may be fairly consistent, stormwater discharges vary dramatically between events. Particularly important is the site specificity as it applies to discharge quality. This precludes the inter-basin transfer of data which is often relied on to make decisions concerning stormwater effect on receiving streams. As costs for the treatment of stormwater can be considerable, it is felt that careful consideration should be given to the need for such treatment.

FIGURE 4
TOC / BOD_5 RELATIONSHIP



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CHARACTERIZATION OF COAL PILE DRAINAGE

By

Doye B. Cox
R. J. Ruane

Special Projects Staff
Division of Environmental Planning
Tennessee Valley Authority

ACKNOWLEDGEMENTS

This study was conducted as part of the project entitled "Characterization of Effluents from Coal-Fired Utility Boilers," and is supported under Interagency Agreement Numbers EPA-IAG-D5-E-721 and TV-41967A between TVA and EPA for energy related environmental research. Thanks are extended to EPA project officers, Julian W. Jones and Ron A. Venezia, and TVA project directors, H. B. Flora and B. G. McKinney. Appreciation is also extended to Randall L. Snipes, F. G. Parker, J. E. Liner, Ralph D. Gillespie, and Roger P. Betson for their aid in the project.

ABSTRACT

Coal pile drainage is produced by rainfall percolation through coal storage piles where it procures the oxidation products of metallic sulfides. To chemically characterize coal pile drainage, sampling and analysis programs are being conducted at two TVA coal-fired steam-electric generating plants. The drainage streams were found to contain high concentrations of acidity to pH 7.0 (as $CaCO_3$), suspended solids, total dissolved solids, iron, manganese and a variety of trace metals. The pH of this drainage remained in the relatively narrow band of 2.3 to 3.1. Transfer of coal pile drainage to an alkaline ash pond appears to provide adequate removal of the above. A rainfall-runoff relationship was developed for prediction of total runoff volumes for specific rainfall events.

INTRODUCTION

Increases in energy use coupled with delays and restrictions on nuclear plants and decreases in supplies of fuel oil and natural gas make increases in coal production and utilization inevitable. Coal, whether it is to be used directly for steam generation, for liquefaction, for gasification or for other processes will have to be stored in huge quantities. The volume to be stored, methods of handling, and the explosive nature of coal dust all dictate outdoor storage. Outdoor storage presents a number of interesting potential problems including blowing coal dust and an esthetically displeasing appearance.

Another potential problem associated with open-air storage is rainfall runoff from the coal storage area. Long before major coal-fired steam-electric plants were in existance, the Welsh were familiar with the acidic character and distinguishing orange color of coal mine drainage. Naturalists have for centuries been aware of the orange-yellow stains that many times accompany coal outcrops. When similar drainages appeared emanating from coal storage facilities at power plants they were largely ignored and passed off as a localized and perhaps natural occurrence. However, with the advent of the environmental movement, industrial discharges came under closer scrutiny. In light of this, characterization of discharges from coal-fired power plants was undertaken. As part of this overall study of potential discharges, a program was designed to provide an adequate characterization of drainage from coal storage piles.

Programs were established at two Tennessee Valley Authority (TVA) coal-fired steam plants. Plant J has a rated capacity of 1700 megawatts with a 90-day coal supply amounting to $\sim1.26 \times 10^6$ cubic yards ($\sim9.6 \times 10^5$ cu m) or 1.2×10^6 tons (1.1×10^9 kg). Plant E has a rated capacity of 1400 megawatts with a 90-day coal supply amounting to $\sim 1.13 \times 10^6$ cubic yards (8.6×10^6 cu m) or 1.08×10^6 tons (9.88×10^8 kg).

Coal for Plant J is mined in eastern Tennessee and Kentucky and transported by truck and rail to the plant site. It is stored prior to any preparation. Coal for Plant E is mined in western Kentucky and is transported mainly by barge. This coal is also stored prior to any preparation. A typical analysis of coal from both plants is presented in table 1.

Table 1

COAL ANALYSIS DRY BASIS

	Plant J	Plant E
	%	
Total Moisture	3.8	4.2
Volatile Matter	34.1	37.7
Ash	17.2	15.0
Fixed Carbon	48.7	47.3
Total Sulfur	2.1	3.9
	Btu	
Btu/lb	12270	12450
Ash Analysis	% of Ash	
CaO	1.4	4.2
MgO	1.1	1.1

BACKGROUND

To ensure uninterrupted generation of electricity, an outdoor coal reserve is maintained at each power plant. This coal supply is available for use in the event normal deliveries are delinquent, temporarily discontinued, or inadequate to meet peak electricity demands. A 90-day coal supply is customarily maintained to provide a sufficient safety factor. Factors which preclude a large coal stockpile include the cost of land required for storage, workmen and equipment needed to maintain the coal storage area, the cost of the larger inventory, and oxidative degradation that occurs when coal is stored for long periods of time. While the physical volume of coal storage required varies with the plant consumption rate, coal piles are typically 25 to 40 feet (8 to 12 m) high and spread over an area 25 to 100 acres (10 to 40 hac). Normally 780 to 2340 cu yds (600 to 1800 cu m) of coal storage are required for every megawatt of rated capacity.

Coal pile drainage results from percolation of rainfall through stored coal. The water quality of the drainage is affected by the leaching of oxidation products of metallic sulfides associated with the coal. The sulfide bearing minerals that predominate in coal are pyrite and marcasite, both iron sulfide ores. Marcasite is unstable and degrades into pyrite. The oxidation of pyrite results in the production of ferrous iron and acidity (FWQA 1970):

$$(1) \qquad 2\,FeS_2(s) + 7O_2 + 2H_2O \longrightarrow 2Fe^{+2} + 4H^{+} + 4SO_4^{-2}$$

This ferrous iron then undergoes oxidation to the ferric state:

$$(2) \qquad 4Fe^{+2} + O_2 + 4H^{+} \longrightarrow 4Fe^{+3} + 2H^{+} + 2OH^{-} \text{ (rate limiting step)}$$

Ferric iron then either hydrolyzes to form insoluble ferric hydroxide producing more acidity:

(3) $Fe^{+3} + 3H_2O \longrightarrow Fe(OH)_3\ (s) + 3H^+$

or can oxidize pyrite directly producing more ferrous iron and acidity.

(4) $FeS_2(s) + 14Fe^{+3} + 8H_2O \longrightarrow 15Fe^{+2} + 2SO_4^{-2} + 16H^+$

The stoichiometry of this reaction reveals that for every mole of ferrous iron oxidized in equation (2) there is a net increase of two moles of hydrogen ion. This net increase in acidity provides hydrogen ions for further oxidation of ferrous iron and subsequent acid production.

As the pH decreases below 5, certain acidophilic, chemoautotrophic bacteria become active. These bacteria, Thiobacillus ferrooxidans, Ferrobacillus, ferrooxidans, Metallogenium, and similar species are active at pH 2.0 to 4.5 and use CO_2 as their carbon source (Silverman 1967). They are the main factor contributing to the oxidation of ferrous iron to the ferric state, the rate limiting step in the oxidation sequence. Their presence is an indication of rapid pyrite oxidation and is usually accompanied by waters low in pH and high in iron, manganese, and total dissolved solids.

Factors that possibly affect production of acidity in coal piles and the subsequent leaching of trace metals are (1) concentration and form of pyritic sulfur in the coal, (2) size of the coal pile, (3) method of coal preparation and cleaning prior to storage, (4) climate, including rainfall and temperature, (5) concentration of $CaCO_3$ and other neutralizing substances in the coal, (6) concentration and form of trace metals in the coal, and (7) the residence time in the coal pile.

Methodology

Plant J--In 1972 a system was installed for collection of coal pile drainage and the subsequent transfer of the drainage to an ash pond (Figure 1). Collection is accomplished by a series of maintained channels around the coal pile which drain into a storage basin. A manually operated pump, an associated piping system, and a secondary maintained channel are components which transfer the drainage to the ash pond. The storage basin is designed to contain the runoff from a moderately small storm at best. Due to this limited capacity, the pump is activated manually at the start of almost all rainfall events and actual detention time in the basin proper is small.

A sampling system (Figure 2) was designed so that pressure in the line which runs from the pump to the ash pond forces a sample into the sample collection barrels. The sample line is composed of tygon tubing with plastic fittings. The sample barrels are plastic garbage cans with an approximate volume of 150 l each. Flowrate of coal pile drainage from the storage basin to the ash pond is approximately 900 gpm (3400 l/m). This flowrate will be refined as more data becomes available. Flow through the sample line was adjusted to approximately 0.025 gpm (0.1 l/m). This arrangement supplies a sample that is a composite of the total volume pumped to the ash pond. Due to the acid nature of the waste and the desire to collect pH and acidity data the sample was not preserved by acidification until the date of collection. Collection was accomplished by first manually stirring the samples and then collecting the samples from a line draining both barrels. Chemical analyses were performed by the TVA Water Quality Laboratory using methods prescribed in Standard Methods for the Examination of Water and Wastewater (APHS 1971), and Manual of Methods for Chemical Analysis of Water and Wastes (EPA 1974).

A rain gage was placed adjacent to the coal pile so that a rainfall/runoff relationship could be developed. This information will be used in design

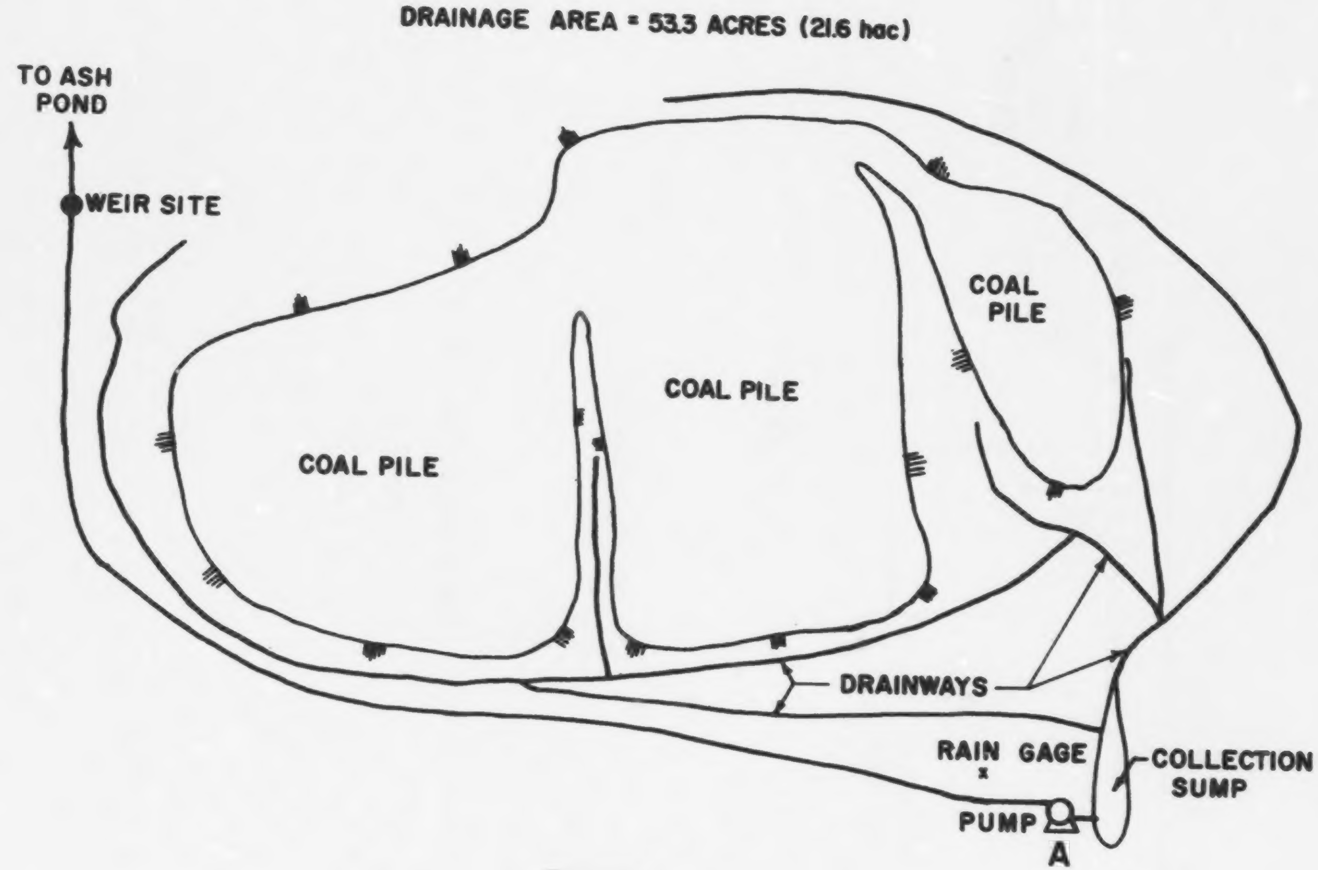
DRAINAGE AREA = 53.3 ACRES (21.6 hac)
TO ASH POND
WEIR SITE
COAL PILE
COAL PILE
COAL PILE
DRAINWAYS
RAIN GAGE
x
COLLECTION SUMP
PUMP
A

FIGURE I

COAL PILE AND DRAINAGE COLLECTION SYSTEM

PLANT J

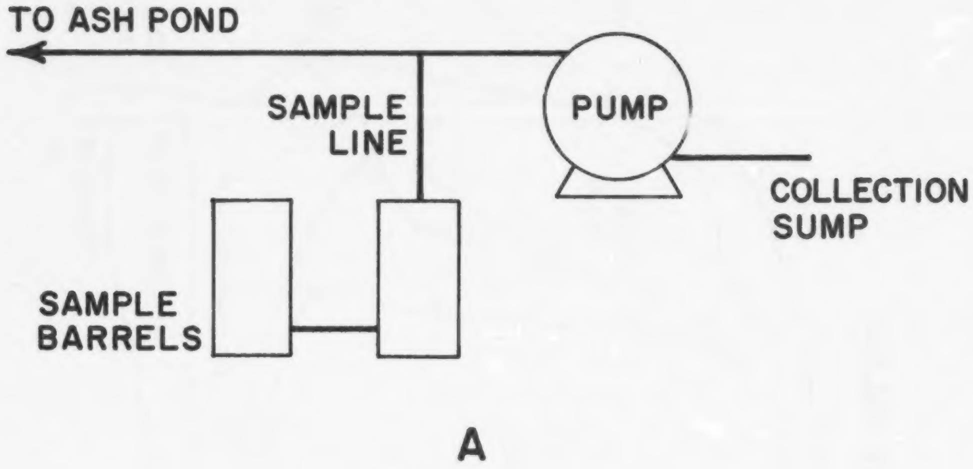
TO ASH POND
SAMPLE LINE
PUMP
COLLECTION SUMP
SAMPLE BARRELS
A

FIGURE 2

SAMPLE COLLECTION SYSTEM

PLANT J

of future storage basins and in estimation of evaporation and percolation losses. Rainfall was compiled on a daily basis, tabulated and compared with hours of pumping time. Pumping rate was determined by placing a temporary weir in the drainage channel downstream from the pump. This installation was subject to only minimal inflow from the immediate vicinity. In cases when intermittant rain occurred over several consecutive days and the pump was in almost continuous operation, the determination of individual rainfall and its concurrent runoff was impossible. Instead, when consecutive days of rainfall occurred, total rainfall and associated pumping over this entire period were considered as one rainfall/runoff event.

Plant E--Drainage from the coal pile at this installation is collected in no systematic manner, though plans for total collection and transfer to the ash pond are under development. Instead the drainage emanates in three distinct directions (Figure 3). Drainages A and B unite at some distance downstream and flow into a holding pond. However, at this point there is significant dilution of the coal drainage. Drainage C quickly spreads out onto a mud flat. Due to the diverse nature of these discharges and the expense of installing and maintaining even temporary flow gages, drainage volume at Plant E was not gaged.

A modified ISCO model 780 automatic water sampler was placed onsite at one of the drainways and a small sample pool constructed (Figure 4). This sampler was equipped with a stage activation device so that the sampler initated sampling with the rise of the storm hydrograph. Samples were collected at hourly intervals and composited. Thus, these samples represent a simple composite of each runoff event. Discreet samples were collected of a single storm event on February 24, 1977. Total rainfall for this event was 2.10 in. (53 mm). These samples were collected at 20-minute intervals and analyzed for pH, acidity,

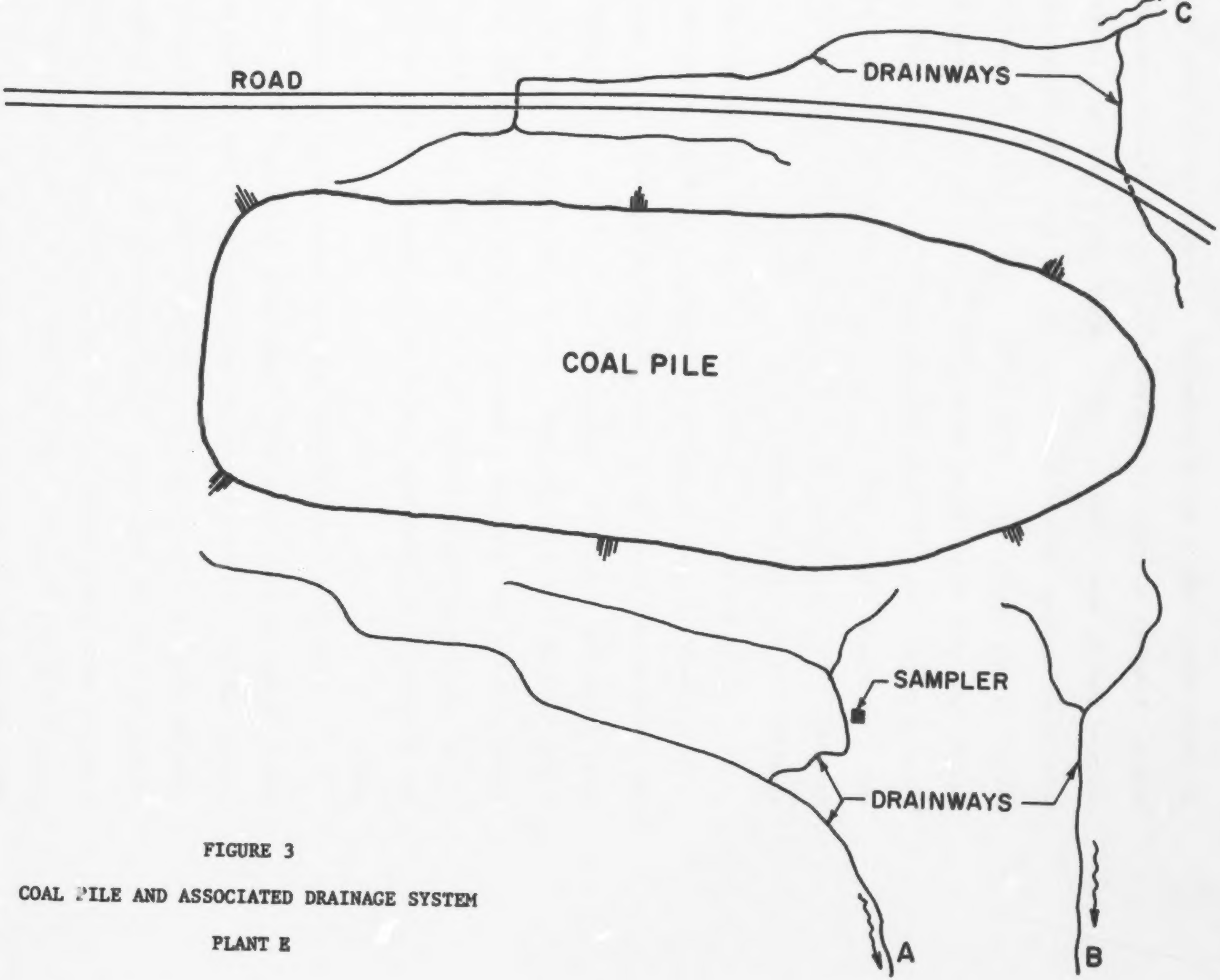
ROAD
DRAINWAYS
C
COAL PILE
SAMPLER
DRAINWAYS
A
B

FIGURE 3

COAL PILE AND ASSOCIATED DRAINAGE SYSTEM

PLANT E

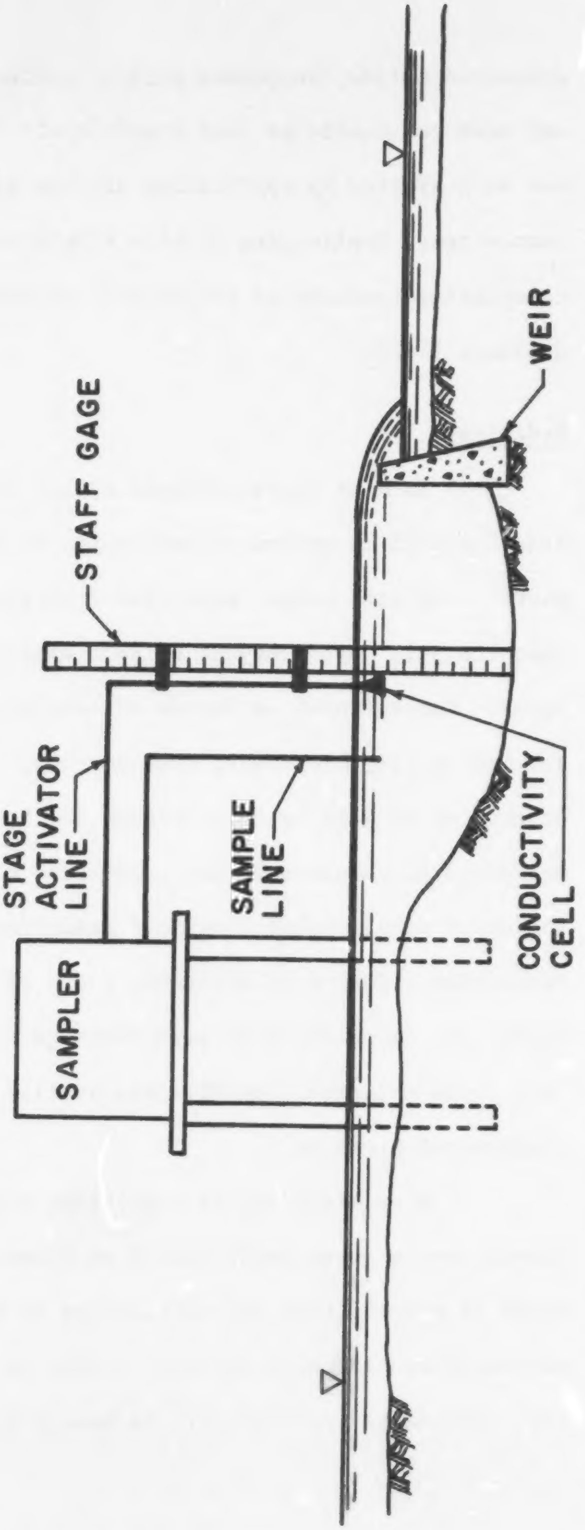
STAFF GAGE
WEIR
STAGE ACTIVATOR LINE
SAMPLE LINE
CONDUCTIVITY CELL
SAMPLER

FIGURE 4

SAMPLE COLLECTION SYSTEM

PLANT E

dissolved solids, suspended solids, sulfate, iron, and manganese. Rainfall was measured onsite so that runoff could be estimated. Loadings of pollutants can be projected by application of this estimate to individual storm event composites. Application of this simple composite—average flow method for calculating loadings of pollutants has been demonstrated to be adequate by Grizzard (1976).

Hydrology

In most cases rainfall either results as surface runoff, percolates into the soil to become ground water, or is lost through evapotranspiration. However, in coal piles, even that fraction of the rainfall that percolates into the pile maybe subject to some evaporation, and no transpiration can occur. Conventional estimates of evapotranspiration used in most hydrological models are, therefore, questionable. Due to these problems and the expense of installing large flumes for long term measurement of flows, detailed hydrological models were not calibrated for use as a part of this study. Instead a simple rainfall/runoff relationship was developed for use at TVA facilities. Such a relationship could be used for estimating detention basin design and calculation of acid loads to the ash pond because rainfall, temperature, wind velocity, humidity are similar throughout the Valley and ridge geophysical province.

A rainfall/runoff regression analysis was performed for data collected over a seven-month period at Plant J. Runoff was calculated by taking hours of pumping time and multiplying by a known pumping rate. Rainfall was monitored continuously onsite. A plot of the regression line and the 95 percent confidence intervals of the mean are presented in Figure 5. This relation

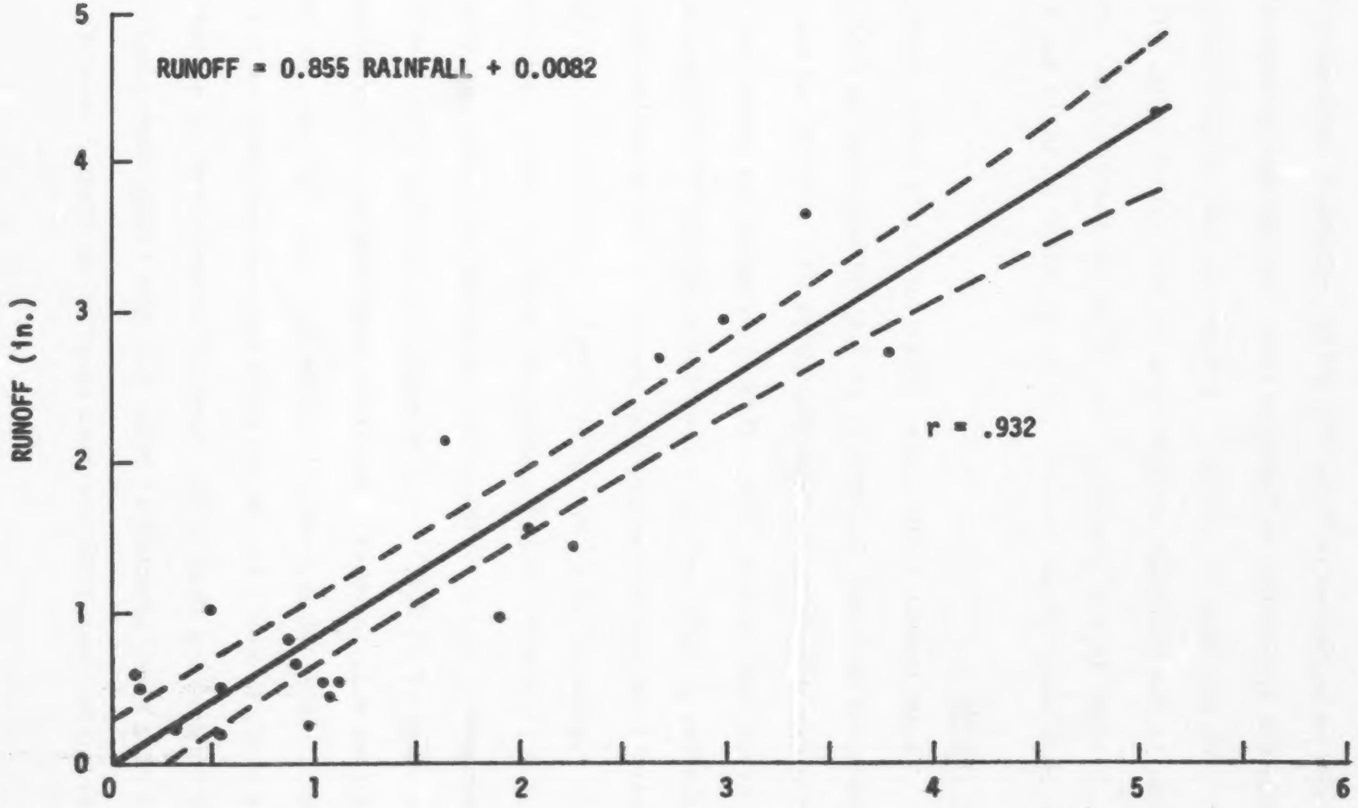

FIGURE 5

REGRESSION OF RAINFALL vs RUNOFF

(Equation 5) can be used to predict the runoff in inches/acre for a given storm event when total inches of rainfall are known.

(5) Runoff (in.) = 0.855 rainfall (in.) + 0.0082

Runoff can be converted to total runoff by applying a drainage area and obtaining the appropriate volumetric term. Losses due to evaporation and infiltration are about 14 percent. Losses decrease slightly at lower rainfalls due to the inclusion of base flow in this relationship. It is, of course, limited in application to coal piles of similar size. Additional factors that could affect runoff include amount of snowfall and soil permeability.

Acidity and pH

Both systems investigated exhibited highly acidic drainages. Acidity was determined as "cold" acidity to pH 7.0 and expressed as $CaCO_3$. Acidity was quite variable in both cases (see table 2). However, pH was within a rather tight band (2.3 to 3.1). This illustrates the point that acidity is not a measure of hydrogen ion but rather a measure of available protons. Means (arithmetic) are quite similar. In fact 21 of the 25 values fall between 2.6 and 3.0. Values of pH presented by Nichols (1974) exhibit a slightly broader range of 2.1 and 3.0. Data presented by Anderson (1976) representing hourly pH measurements over a 3-week period contained pH reading ranging from 2.2 to 5.8. A range of pH 2.4-3.0 was presented by Matsugu (1976) for 67 grab samples of coal pile leachate. For these same samples acidity varied from 10 to 120 meq/l. Thus, it appears that pH of coal pile drainage, at least for eastern coal, is generally in the relatively narrow range of 2.2 to 3.1. Another interesting observation involves comparison of pH values obtained at Plant J with those obtained at Plant E. Even though coal supplied to Plant E was high sulfur coal (>3%) and coal supplied to Plant J moderate in sulfur

Table 2

MEANS AND RANGES OF PROJECT DATA FROM PLANT J AND PLANT E

Plant		pH	Acidity (mg/1 $CaCO_3$)	Sulfate (mg/1)	Dissolved Solids (mg/1)	Suspended Solids (mg/1)	Fe (mg/1)	Mn (mg/1)
J	Range	2.3–3.1	300–7100	1800–9600	2500–16000	8.0–2300	240–1800	8.9–45
	Mean	2.79	3400	5160	7900	470	940	28.7
	N	19	18	18	18	18	19	19
E	Range	2.5–3.1	860–2100	1900–4000	2900–5000	38–270	280–480	2.4–10.0
	Mean	2.67	1360	2780	3600	190	380	4.13
	N	6	6	6	6	6	6	6
E (Discrete Storm)	Range	2.5–2.7	300–1400	870–5500	1200–7500	69–2500	62–380	0.88–5.4
	Mean	2.63	710	2300	2700	650	150	2.3
	N	14	14	14	14	14	14	14

content (1-3%) as classified by EPA (Oct. 1976) pH of the drainage was similar for both plants. Caruccio (1976) has shown that total sulfur concentration is not directly related to acid formation from pyritic material. A second explanation involves maintenance of an optimum pH range (2-4) of the autotrophic bacteria responsible for pyrite oxidation as explained by Schnaitman (1969). It is interesting to note that acidity is higher at Plant J than at Plant E even though pH's are similar. In essence, any substance capable of donating protons (most metals, many naturally occurring organic compounds) will be measured as acidity.

Solids

Total suspended solids concentrations are of primary interest in characterization of coal pile drainage. Elevated concentrations occur when rainfall/runoff suspends coal fines in the pile. This is generally not a problem during base flow conditions but occurs during runoff events at levels up to 2300 mg/1.

Suspended solids concentrations at Plant J ranged from 8 to 2300 mg/1 with a mean of 470 mg/1. It should be noted, however, that these samples were collected after the sample had passed through a collection sump where some settling occurred. At Plant E where direct runoff was collected as a single composite sample for each storm event, the mean and range of suspended solids concentrations were somewhat lower. However, when the discrete-within-storm-event samples were examined the range and mean were similar to that obtained at Plant J indicating that minimal settling occurred in the collection sump at that installation. Suspended solids values much higher than this were presented by Matsugu (1976).

Total dissolved solids concentrations were somewhat higher at Plant J than Plant E even when the discrete-storm-event samples were considered. An inspection of the data reveals that most of the total dissolved solids are sulfate salts. Hence, higher total dissolved solids concentrations are a consequence of enhanced pyritic oxidation via equations 1 and 4. This data complements the acidity and pH data in suggesting that enhanced pyritic oxidation is occurring at Plant J.

Iron and Manganese

These metals are often discussed simultaneously due to their similar behavior in water. Both are increasingly soluble with decreasing pH, exist in both the reduced and oxidized state, and form coatings on particles that may limit solubilities of other metals (Jenne 1968). Typically iron and manganese concentrations in pyritic systems are quite high. Iron minerals are the substrate necessary for acid production (Equations 1-4). As such, lower concentrations would be expected only where pyritic oxidation is repressed or where pH is not depressed sufficiently to allow for iron solubility. Values for iron presented by Nichols (1974) ranged from 0.17 to 93,000 ppm with a mean of 19,500 ppm. A somewhat narrower range of 10 to 5,300 ppm and lower mean of 1,150 was presented by Anderson (1976).

Iron concentrations at both plants are lower in range and mean than encountered by these other investigators. Concentrations at Plant E ranged from 280 to 480 mg/l with a mean of 380 mg/l. This is considerably higher than the discrete storm samples which ranged from 62 to 380 mg/l with a mean of 150 mg/l. Concentrations of iron at Plant J were higher with a range of 240 to 1800 mg/l and a mean of 940 mg/l.

Manganese concentrations reported by Anderson (1976) ranged from 4.5 to 72.0 mg/l with a mean of 17.1 mg/l. Somewhat lower concentrations were presented by Matsugu (1976), ranging from 3.4 to 12 mg/l with a mean of 6.9. Levels at Plant J (Table 1) were comparable to those presented by Anderson. Values for Plant E were somewhat lower.

Trace Elements

There is a paucity of information available on trace element concentrations in coal pile drainages. Trace elements of environmental concern in coal have been identified by EPA (October 1976) and are presented in table 3. These constituents, with the exception of Yttrium were analyzed in drainages from both plants. In addition, several other elements including aluminum and chromium were analyzed on several samples. Results of analyses for selected trace elements are presented in table 4. Several other trace elements were also analyzed in drainages from both plants. Of these elements lead, barium, and titanium were low or consistantly below the limits of detection. Levels of antimony were above detection limits in several instances but were not included because of a question of their significance to freshwater aquatic life. When an element was below detection limits the detection limit was used for statistical purposes. It is interesting to note that most means of trace element concentrations at Plant J are 3 to 8 times higher than those at Plant E.

Table 3

TRACE ELEMENTS IN COAL
(EPA, October 1976)

Element	Range (μg/g)	Element	Range (μg/g)
Beryllium	0-31	Selenium	0.4-8
Nickel	0.4-104	Yttrium	0.1-59
Copper	2-185	Cadmium	0.1-65
Zinc	0-6000	Mercury	0.01-1.6
Arsenic	0.5-106	Lead	4-218

Table 4

MEANS AND RANGES OF TRACE METAL DATA
FROM PLANT J AND PLANT E

Plant		Cu	Zn	Cd	Al	Ni
				mg/1		
J	Range	0.43–1.4	2.3–16	<.001–<.001	66.0–440	0.74–4.5
	Mean	0.86	6.68	<.001	260	2.59
	N_D	0	0	19	0	0
	N	19	19	19	19	19
E	Range	0.01–0.46	1.1–3.7	<.001–0.003	22.0–60.0	0.24–0.46
	Mean	0.23	2.18	0.002	43.3	0.33
	N_D	0	0	2	0	0
	N	6	6	6	6	6

Plant		Cr	Hg	As	Se	Be
				mg/1		
J	Range	<.005–.011	<.0002–.0025	.005–0.6	<.001–.03	0.03–0.07
	Mean	.007	.0004	0.17	0.006	0.044
	N_D	11	12	0	4	0
	N	17	20	19	18	18
E	Range	<.005–.011	0.003–.007	0.006–0.046	<.001–.001	<.01–0.03
	Mean	0.007	0.004	0.02	0.001	0.014
	N_D	3	0	0	3	3
	N	6	5	4	4	4

N_D = Number of samples below detection limits.

Concentrations of copper are higher than criteria for Plant J (EPA, July 1976) if discharged untreated. These levels are, however, lower than those presented by Nichols (1974) or Anderson (1976). Concentrations for Plant E are lower still and don't appear to be significant from a water quality standpoint.

Levels of zinc are also high with respect to ambient quality. The mean concentrations of 6.68 mg/l and 2.18 mg/l at Plant J and Plant E are similar to the means of 5.9 presented by Nichols (1976) and 3.67 presented by Anderson (1976), respectively. The public water supply criteria established by EPA (July 1976) is 5 mg/l.

Cadmium concentrations are quite low in drainages from both plants. At Plant J no samples exceeded detection limits. At Plant E four of the six samples exhibited detectable concentration but none were above water quality criteria (EPA, July 1976).

Aluminum is included as a toxic substance by the National Academy of Science (1972) in developing proposed water quality criteria but eliminated by EPA (July 1976) in their development of finalized criteria. Thus, the significance of aluminum as a toxic substance is in question. Mean concentrations of 260 mg/l and 43 mg/l were found respectively at Plants J and E.

Concentrations of nickel are also above levels found in surface water (National Academy of Science, 1972) but are significantly less than aluminum.

Chromium concentrations were well below established criteria at both plants and pose no threat to the aquatic community or man.

Toxicity of beryllium like several other metals is inversely related to the hardness of the solute. Coal pile drainage is quite hard (the mean calcium and magnesium concentrations for Plant J were 300 mg/l and 230 mg/l, respectively). Levels of beryllium are well below established criteria for waters of this hardness (EPA, July 1976).

Mercury concentrations were an order of magnitude higher at Plant E than at Plant J. Levels were found at both plants that exceed established water quality criteria (EPA, July 1976).

Arsenic levels in drainage from Plant J ranged from 0.005 to 0.6 mg/l with a mean of 0.17 mg/l. These values generally exceed established criteria while those concentrations found at Plant E generally did not.

Selenium concentrations behaved similarly to those of arsenic in that Plant J generally exceeded criteria while Plant E did not. This is significant since selenium and arsenic exhibit antagonistic toxicities (Levander 1976).

Mass Input vs. Output

Mass flows of several constituents were calculated at Plant J for the month of June 1976. The total flow for this month was 13 MG (49 Ml). Runoff from the coal pile during this period contained 50 tons (4.5×10^4 kg) of iron, 17 tons (1.5×10^4 kg) of aluminum, 1.8 tons (1.6×10^4 kg) of manganese, 335 lbs (152 kg) of nickel, and 127 lbs (58 kg) of copper along with large quantities of sulfate, dissolved solids, suspended solids, and hardness.

In order to assess the contribution of rainfall to the coal pile system, a rainfall sample was collected during a storm that occurred on June 29-30. This storm had a duration of 33 hours with a total precipitation of 1.35 in. (3.43 cm). Total precipitation for June was 7.99 in. (20.3 cm).

Concentrations of several constituents were analyzed in the rainfall samples and loadings were extrapolated for the month of June. Calculated values were: iron 13.5 lb (6.1 kg), aluminum 19.4 lb (8.8 kg), manganese 1.0 lb (0.5 kg), nickel 4.9 lb (2.2 kg), and copper 6.7 lb (3.0 kg). Thus, contaminants in rainfall appeared to be insignificant.

Treatment

TVA plans to route all coal pile drainage to ash ponds where dilution/neutralization/adsorption processes may take place. However, if the ash sluice has an insufficient amount of base available for neutralization or the pH of the ash sluice—coal pile drainage mixture is too low (<8.5-9.0)—precipitation of many metal hydroxides will not occur (Sittig 1973). When pH is too low for precipitation dilution and particle adsorption are the major processes for reducing trace metals concentrations within the ash pond.

At Plant J, the ash pond effluent pH has exhibited a periodic character. The pH fluctuates from the 7.0-8.5 range in summer-fall to the 3.5-4.5 range in winter-spring. Total hardness, alkalinity, and total dissolved solids also vary periodically. In the past, this phenomenon has been attributed to changes in the raw makeup water for ash sluicing since water known to contain lower alkalinity is used for this purpose during the spring. It was felt that coal pile drainage may also play a role in establishing the seasonal character of the ash pond effluent. However, there is a decrease in total dissolved solids concentrations with decreasing pH in the ash pond effluent which would indicate that this is not the case. Trace metals are monitored monthly in TVA ash pond effluents for plants in Tennessee and quarterly in other plants. Comparison of trace metal concentrations in ash pond effluent at Plant J where coal pile drainage is routed to the ash pond with other ash ponds not receiving these inputs reveals no obvious differences in mean effluent concentrations of trace metals. In addition, since mean effluent concentrations of trace metals are similar (see Table 5) at these plant even through effluent pH's are dissimilar (some are alkaline, some neutral, some acid), the adsorption/ dilution processes must equilibrate these concentrations. To illustrate the importance of ash pond dilution in reducing the concentrations of pollutants in coal pile drainage, yearly and daily flows of both waste streams can be compared at Plant J. The total yearly ash sluice flow for 1976 was approximately 9.8 x 10^9 gal. (3.7 x 10^{10} l). An estimation of yearly coal pile drainage can be arrived at by applying the average annual precipitation, 51 in. (129.5 cm), to equation 5 and using the drainage area given in Figure 1. This produces an estimation of 6.3 x 10^7 gal. 2.3 x 10^8 l) or 0.64 percent of the average annual ash sluice flow. On a daily basis the average ash sluice flow (calculated from 1976 data) is 2.6 x 10^7 gal. (1 x 10^8 l). An estimation of coal pile drainage at this plant is best arrived at by assuming continuous operation of the coal pile drainage pump for a 24-hour period. This estimate is 1.3 x 10^6 gal. (4.9 x 10^6 l) or 5 percent of the average daily ash sluice flow. At a plant where no collection basin-pump system is operative, an estimation of coal pile drainage volume could be arrived at by applying equation 5 using an appropriate design storm. More information regarding these processes and the effects of pH on trace metal concentrations in ash pond effluents is being developed by an EPA/TVA concurrent project. Final determination of the role of coal pile drainage in affecting ash pond effluents would require a detailed mass balance study of the ash pond-coal drainage system.

In cases where dry ash disposal is employed, other treatment technologies may have to be used. Due to the similarities between coal pile drainage and acid mine drainage many of the treatment methods used for the

TABLE 5

ASH POND EFFLUENT DATA*

Plant	J	E	C	A (Fly Ash)	A (Bottom Ash)	D
				CONCENTRATION (SU)		
pH	6.0	11.2	7.2	4.2	7.2	8.5
				mg/l		
Fe	2.4	0.16	3.9	2.2	5.2	0.32
Mn	0.38	0.01	0.19	0.49	0.17	0.02
Cu	0.11	0.08	0.06	0.33	0.07	0.03
Zn	0.07	0.05	0.14	1.4	0.08	0.03
Cd	0.001	0.001	0.004	0.038	0.001	0.001
Ni	0.05	<0.05	0.06	0.08	0.06	0.06
Cr	0.005	0.017	0.008	0.072	0.007	<0.005
Hg	0.0003	0.0002	0.005	0.0003	0.0005	0.0002
As	0.041	0.028	0.018	0.011	0.007	0.034
Se	0.004	0.007	0.007	0.002	0.002	0.07

*Average of quarterly data 1973-1975.

latter drainage stream would be applicable. Methods most widely used are lime or limestone neutralization. However, reverse osmosis (Rosehart 1973), and sulfide precipitation (Ross 1973) have been investigated. Fly ash neutralization appears to be quite feasible when the ash is sufficiently alkaline.

Sediment samples were taken from the bottom of channels draining the coal pile. These samples consisted of mud, coal fines, pyrite chips, and an amorphous yellow precipitate. There were, in many places, green precipitates covering the small pebbles. These sediment samples were examined for iron oxidizing bacteria. The genus Thiobacillus was identified in all samples. The amorphous precipitate appeared to be elemental sulfur, an amorphous pyrite, or ferric chloride. This precipitate appeared on the surface of gullies eroded into the sides of the coal pile. The precipitate only appeared on the gully bottom and was not visible after removing approximately one centimeter of the fines forming the gully bottom. If this was indeed elemental sulfur, its source can be attributed to the bacterial oxidation of pyrite where it has been identified as an intermediate in the oxidation of sulfide to sulfate. Identification of iron oxidizers indicates the possibility of inhibition of the responsible organism for drainage control. Investigators working on control of acid mine drainage, a waste also mediated by Thiobacillus, have reported dramatic decreases in acid production rates when bacterial inhibitors were employed (Shearer 1968). One proven inhibitor is ferrous iron in high concentrations. Application of an inhibitor for reducing the rate of acid production could be accomplished by application along with sprinkling for dust control. This method of control could be particularly appropriate where dry ash disposal is employed.

Conclusions

Coal pile drainage is a highly acidic waste stream containing high concentrations of a wide variety of inorganic constituents. Further, the acidity of this waste stream may not be governed by sulfur content of the coal. However, transfer of this drainage to an ash pond where neutralization/dilution/adsorption phenomena take place appears to provide adequate treatment.

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MEASUREMENT OF NON-POINT SOURCES FROM A COAL-FIRED UTILITY AND THE IMPACT ON RECEIVING WATERS

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ABSTRACT

Non-point source water pollution has become a growing concern in the United States because in many areas non-point source pollution overwhelms and negates the reductions achieved through control of point sources. TRC - THE RESEARCH CORPORATION of New England was retained by the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency to perform, as part of a contract to develop fugitive emissions management techniques, industrial runoff assessments of the coal-fired utility and iron and steel industries.

This paper describes the coal-fired utility measurement program and field survey results. The survey was performed at two utility plants in Pennsylvania. One plant is near the headwaters of the Allegheny River in Warren, Pennsylvania. The second plant is on the Delaware River in Portland, Pennsylvania near the Pocono Mountains. The survey included measurement of overland runoff from non-point sources and river sampling upstream and downstream of the plant site. The non-point sources sampled were stormwater runoff and leachate from coal storage piles (an infinite source) and stormwater runoff from impervious areas such as parking lots and roofs which were covered with dust fallout from coal handling and ash handling operations (a finite source).

The data survey indicated that non-point source pollution from the utilities had little impact on the two rivers compared to the impact from sources upstream of each site. Although the river mass loadings were higher (due to increased flow), the data showed no statistical difference in mean concentrations of upstream versus downstream pollutant levels in

either dry or wet weather conditions. Runoff at Warren showed dry weather leachate from the coal pile had a greater mass loading than storm event mass loading. The site location at Warren and the rain event at Portland, contributed to the variability of river data.

The field survey results indicate that for a program to be cost-effective, the sampling must be supplemented with modeling. Thus, before regulations can be generated for industrial stormwater runoff, more problem definition (sampling and modeling) must be performed.

INTRODUCTION

As most industries and many municipalities are meeting the point source standards of the interim goal of 1977, the effect of non-point source pollution on water quality is gaining more attention. The National Commission on Water Quality reported that "non-point pollutant sources are significant to the Commission's study because they may in some instances overwhelm and negate the reductions achieved through point source effluent limitations"[1]. Based on these findings, the Commission recommended to Congress that "control or treatment measures shall be applied to agricultural and non-point discharges when these measures are cost-effective and will significantly help in achieving water quality standards"[2].

In January 1976, TRC - THE RESEARCH CORPORATION of New England was retained by the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency to evaluate waterborne fugitive emissions (non-point sources) in relationship to industrial activities. The objectives of the program included:

- An evaluation of industrial sources which might contribute to non-point source pollution.
- An assessment of present day sampling techniques for non-point sources.
- A review of existing mathematical models for predicting non-point source pollution.
- An evaluation (including a field program) of non-point source pollution from the coal-fired utility and iron and steel industries.
- The adaptation of a mathematical model for predicting non-point source pollution from an industrial site.

This paper presents the highlights of the coal-fired utility measurement program. The main objective of this program was to quantify and qualify runoff from two coal burning utilities and to measure the effect of runoff on the receiving waters.

INDUSTRY SELECTION

Why should the runoff from the coal-fired utility industry be measured?

Electrical energy is generated from fossil and nuclear fuels at approximately 1,000 sites in the United States. At these sites, coal provides approximately 54% of the total heat input for electricity generation. In 1974, this amounted to a coal usage rate of 328 million metric tons per year. Increasing demands for energy self-sufficiency are likely to push coal usage up to 454 million metric tons per year by 1990. Subsequently, in 1990 coal storage, typically a 100-day supply, will increase from the current 100 million tons to 138 million tons. Land use for coal storage at electric facilities will increase to 81 million square meters from an approximate 1974 total of 58 million square meters. Stormwater runoff from coal storage piles will also increase 38% to an estimated yearly total of 100,000-140,000 cubic meters per year[3,4].

The effect of stormwater runoff on the receiving bodies will become more pronounced as water quality improves through regulation of point sources. These projections are the basis for selecting the coal-fired utility industry for a sampling program.

TEST PLAN

TRC developed a test plan to quantify the pollutants associated with stormwater runoff and to assess their effect on the receiving waters. The field study was designed to determine:

1. Background conditions in the receiving water prior to a storm event.
2. Volume of and pollutant concentrations in stormwater runoff as a function of time for the storm event.
3. Post-storm effect of the runoff on the receiving water.

The following additional information was required to apply to the predictive model development:

1. Air temperature and humidity
2. Dustfall accumulation
3. River flow rates
4. Surface permeability

To quantify the effect of stormwater runoff on the receiving body, a sampling station would be installed upstream of potential plant site effects and a second station would be installed downstream. Theoretically, comparison of the data taken at these two sampling sites would show the effect of runoff on the river water quality. The sampling sites were to be placed at locations where representative samples could be taken with respect to the river cross-section and depth. To allow adequate mixing of the runoff in the river, placement of the downstream site was most critical.

To characterize the stormwater runoff, it would be necessary to intercept some amount prior to its entering the river. As each runoff basin was identified, sampling plugs would be deployed to catch representative samples during a storm event. The flow rate of runoff would be quantified to establish the time variable pollutant load on the river.

Composite samples would be collected from the river sampling stations and runoff sites every ten minutes for the first 90 minutes of a storm event. Half-hour samples would be collected after the first 90 minutes. Each sample would be composited from five grab samples taken in a proportionally smaller time period. Thus, five two-minute grab samples would be composited to give a two liter ten minute sample, etc. During dry periods before and after storms, samples would be collected hourly from the upstream and downstream sites.

The pollutants analyzed in this program are listed in Table 1.

TABLE 1

PARAMETERS MEASURED IN UTILITY PROGRAM

pH	Acidity/Alkalinity
Dissolved Oxygen	Sulfate
Total Suspended Solids	Iron
Total Dissolved Solids	Aluminum
Temperature	Manganese

SITE DESCRIPTIONS

Two coal-fired steam electric generating facilities in Pennsylvania were chosen for the field study to identify and quantify runoff characteristics. These utilities were selected because they were located on rivers which had good water quality. Specific characteristics of each site are shown in Table 2.

The Warren Station of the Pennsylvania Electric Company in Warren, Pennsylvania is a small generating plant (84 Mw) and is used primarily as a peaking facility. It is located on the Allegheny River below the Kinzua Dam. This dam regulates the river flow at approximately 56 cubic meters/sec (cms) with an average velocity of 0.3 to 0.6 meters/sec. Bituminous coal is delivered by truck to the station on a daily schedule from mines in Clarion County, Pennsylvania.

Figure 1 shows the site layout for the Warren Station. Coal pile runoff is channeled to a drain pipe by a drainage ditch that parallels unused railroad tracks next to an access road for the coal trucks. (The road and tracks lie between drainage ditch and river on Figure 1.) The drain pipe continually drains small quantities of leachate during dry periods and substantial quantities of runoff during rainfall events. All runoff from the coal pile must pass through the drain pipe for discharge to the river. The paved access road is used by coal trucks to enter and leave the coal unloading area. The road is covered with coal dust and earthen materials, although the pavement is still visible through the accumulation. The material is washed off during rainfall events. The water drains across the road through a rockstrewn area of rubble approximately 12 meters wide to the river bank. There are several distinctly

TABLE 2

CHARACTERISTICS OF THE TWO SAMPLING SITES USED IN THE SURVEY

Utility	Pennsylvania Electric Co.	Metropolitan Edison
Plant	Warren Station	Portland Station
Location	Warren, PA	Portland, PA
Capacity Mw output, net	84	410
Coal		
Usage (metric tons/yr)	315,000 est. 1974	840,000 est. 1974
Source	Clarion Co., PA	PA & W. VA
Storage, metric tons	27,200	172,000
Sulfur %	1.84	1.47
Iron %	0.35	0.38
Manganese %	0.003	0.004
Aluminum %	0.56	0.37

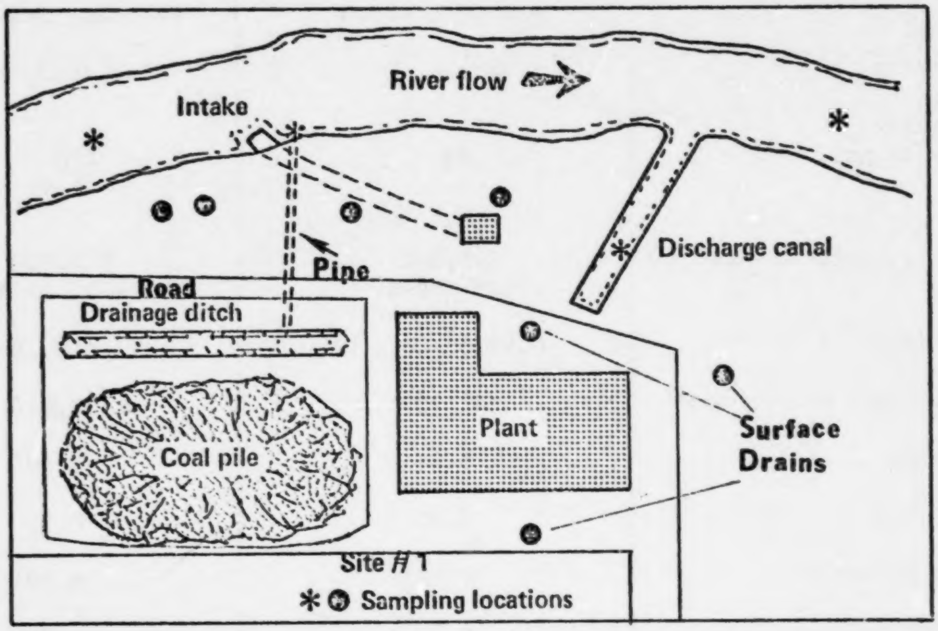
River flow
Intake
Discharge canal
Pipe
Road
Drainage ditch
Coal pile
Plant
Surface Drains
Site # 1
* ● Sampling locations

Figure 1: Site Layout with Sampling Locations-
Warren Station of Pennsylvania Electric Co.,
Warren, PA

visible areas where this road dirt and coal dust are carried to the river. Vegetation is nonexistent in these drainage areas. Surface drains on paved areas around the plant discharge into the main cooling water discharge canal. The surface drains are not effective in collecting stormwater due to the irregular pavement surface.

During the sampling period, the Allegheny River had a flow rate of 56 cms at the sampling sites. The river water was generally close to air temperature and contained noticeable suspended material such as silt and detritus. Plant cooling water was discharged at a rate of 3.6 cubic meters per second into the discharge canal. A delta which split the discharge in two segments had previously formed at the mouth of the canal.

The Portland Station of Metropolitan Edison Company is located in Portland, Pennsylvania on the Delaware River. This 410 Mw station is much larger than the national average of 150 Mw and is used as a baseload station. Bituminous coal is delivered by railroad car from Pennsylvania and West Virginia mines.

Figure 2 shows the site layout for the Portland Station. A substantial portion of the stormwater runoff from the coal pile is intercepted by the ash settling pond and never flows into the river. One sector of the runoff does go to a surface drain and is discharged with parking lot and road runoff into the river. Fly ash is kept on the north side of the plant. There was little fly ash stored during the sampling period. Stormwater runoff from this site washes directly into the river.

During the sampling period, the Delaware River had a flow rate of 300 cms and an average velocity of .3 m/sec. The water was generally very clear and much colder than prevailing air temperatures. The river

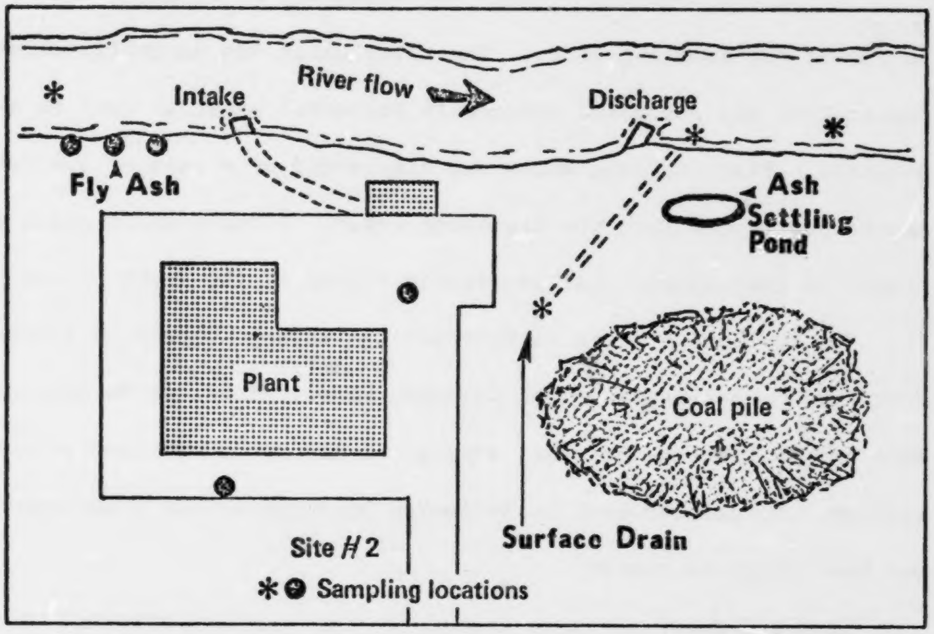
River flow
Intake
Discharge
Fly Ash
Ash Settling Pond
Plant
Coal pile
Surface Drain
Site #2
* ● Sampling locations

Figure 2: Site Layout with Sampling Locations-Portland Station of Metropolitan Edison Co., Portland, PA

height and turbidity changed rapidly with rainfall activity in its watershed. The plant cooling water was discharged near mid-river from a subsurface discharge tunnel at an average rate of 5.4 cubic meters per second.

WARREN SAMPLING PROGRAM

The test plan was implemented at Warren without major difficulties. An upstream site was established approximately 152 meters upstream of the cooling water intake, 7.6 meters from the river's edge. This location was well upstream of the runoff area from the access road. An air-filled buoy was used to suspend the pH/DO and temperature sensors and the sample line at about half-depth, 1.2 meters above the bottom. Dissolved oxygen (DO), pH and temperature were measured with a Model ODEC Aqua Monitor. These data were recorded on a strip chart recorder during rainfall periods.

River samples were collected with an ISCO Model 16800L Sequential Sampler. It was programmed to collect 200 ml grab samples every minute to provide a two liter composite every ten minutes during the first 90 minutes of a rainfall period. From the 90th minute to the storm's end, the sampler was programmed to collect 70 ml every minute to give a two liter sample every half hour. During dry periods, the sampler collected 70 ml every two minutes to give an hourly composite of two liters. The sequentializer was designed to provide backflushing before and after each sampling sequence to preserve the time integrity of the sample. A river depth profile was also made at this location as part of the predictive model development.

The downstream site was secured approximately 152 meters downstream from the cooling water discharge-river interface, 46 meters from the river's edge. Although the turbulent main flow of the river appeared to be on the opposite side, a rudimentary mixing test indicated the sampling location was adequate. An inflatable raft was used to suspend the sensor probe and sample line at two meters, approximately mid-depth. The ISCO Sequential Sampler was mounted on the raft since the distance to shore was too far to run a sample line and maintain sample time integrity. An Orbisphere Dissolved Oxygen meter and chart recorder housed onshore in a tent were used to measure dissolved oxygen and temperature. River samples were taken in the same time sequence as the upstream samples. A recording rain gauge was installed at this site to record the rainfall rate during storm events. A river depth profile was also conducted at this location.

The mixing test was also performed to aid in the model development. One dozen oranges were set adrift just above the upstream site and their journey was timed past several landmarks and past the downstream site. After traversing the rapids (approximately 75% of the distance from the upstream site to the downstream site), the oranges dispersed across the river fairly evenly. It was concluded that the downstream site was adequately placed to obtain representative data.

The runoff drainage areas were well-delineated by the appearance of vegetation between the road and the river. It was difficult to set the sampling plugs vertically into the rocky, rubble-strewn surface, so they were installed in the ground at a slight horizontal angle with the screened opening facing uphill. Approximately 50 plugs were distributed in the three main drainage areas and were kept covered with tape until a rainfall event started. A compositing bucket was placed under the coal pile drain pipe and an ISCO Sequential Sampler was used to collect runoff samples from this bucket. In operation, the sampler intake was continually plugged with push-along solids, and the sampler was replaced by manual sampling.

PORTLAND SAMPLING PROGRAM

The program test plan remained basically unchanged for the Portland survey, but modifications in implementing it were necessary to reflect the differences between the two sites.

At Portland a small area of land north of the plant is used for fly ash storage during winter months. Runoff from this area drains under the plant fence and into the river. The upstream station was placed just upstream from this location approximately nine meters from the shore. An air-inflatable raft was anchored at the upstream site to hold the sensors and sample lines at mid-depth, approximately three meters below the surface. The swift current, local turbulence and rocky bottom created great difficulty when personnel attempted to anchor the raft to its station. Broken and slipped moorings hindered the data-gathering effort at this site throughout the program.

An ISCO Sequential Sampler was used to collect river samples in exactly the same fashion as at the Warren site. In place of the ODEC Aqua Monitor, an Orbisphere dissolved oxygen and temperature meter was used for those parameters. A battery-powered chart recorder was used to record these data during a storm event.

The lower station was established approximately 30 meters downstream from the cooling water discharge tunnel, approximately 230 meters from the upstream site. An identical instrumentation and sampling arrangement as at the upstream site was used.

The coal pile runoff drained to both the ash pond and the storm sewer. A portion of the runoff to the storm drain was intercepted for sampling. Initially, an ISCO Sequential Sampler was installed in the storm drain, but large coal particles continually plugged the sample intake line and pump. To solve this problem, sampling plugs were placed in an array around the storm sewer inlet. Approximately 25 sampling plugs were also deployed in the drainage basin of the fly ash storage area. As with the sequential samplers, samples were collected every ten minutes for the first 90 minutes, and every half hour for the duration of the storm event.

During the one storm event sampled at Portland, river conditions hampered sampling, since the only access to the river sites was by boat. Runoff flow measurements were unsuccessful due to effluent turbidity which masked the dyes and the complexity of storm drains which delayed and trapped velocity markers. A second storm could not be sampled at this site due to a prolonged dry spell, followed by the beginning of cold weather and freezing conditions.

RESULTS OF FIELD SURVEYS

Despite the less than desirable amount of storm activity at Warren and Portland, enough data were collected to show some interesting effects. From the analyses of the coal pile runoff and receiving waters during dry and wet weather, some general characterizations can be made.

The laboratory analyses of the field data during dry and wet periods at all sampling stations show a broad range of values. These ranges of values were substantial enough to mask any apparent relationships between sites and sampling locations. Several statistical summaries have been prepared for selected pollutants during dry and wet periods at the two sampling locations in the receiving body. These summaries included arithmetic means, standard deviation, coefficients of variation and best estimates of variance to provide the statistical basis for comparisons of results. These tests were performed within 95% confidence limits for the selected pollutants of interest.

The calculations were done using two-tailed tests with non-detected values distributed proportionally between 0 and the limit of detection for the specific pollutant. It was assumed that the distribution of the data was approximately similar to a normal distribution. A plot of several sets of data on normal probability coordinates confirmed this assumption. No attempt was made to evaluate the runoff data statistically.

WARREN RESULTS

Table 3 shows the range of pollutant concentrations at the various sampling locations at the Warren Station. The only significant observation is that the pollutants in the coal pile discharge pipe are more concentrated during dry weather (leachate) than wet (runoff), as would be expected.

The downstream pH values do appear lower under both wet and dry sampling conditions. More data are necessary to establish a cause and

TABLE 3

RANGE OF POLLUTANT CONCENTRATION AT THE SAMPLING LOCATIONS AT WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN, PA AUGUST - SEPTEMBER, 1976

Pollutant	RANGE OF POLLUTANT CONCENTRATIONS, mg/1					
	Upstream		Downstream		Coal Pile Discharge Pipe	
	Dry	Wet	Dry	Wet	Dry	Wet
Total Suspended Solids	1 - 21	2 - 5	1 - 11	2 - 12	12 - 19000	1700 - 13000
Total Dissolved Solids	100 - 170	60 - 130	80 - 180	-	2300 - 21700	2300 - 115000
Iron	.14 - .40	.09 - .17	.06 - .34	.09 - 1.03	160 - 23500	700 - 1400
Aluminum	N.D.[1]	N.D.[1]	N.D.[1]	N.D.[1] - 26.6	20 - 1800	70 - 100
Manganese	.013 - .090	.025 - .040	N.D.[2] - .040	.030 - .060	2 - 100	9 - 15
Sulfate	11 - 20	12 - 17	11 - 22	12 - 24	90 - 57000	1600 - 2700
Total Alkalinity @ $CaCO_3$	38 - 48	38 - 42	36 - 45	40 - 41	-	-
Total Acidity @ $CaCO_3$	-	-	-	-	200 - 38000	1900 - 2900
pH	6.77 - 7.80	6.60 - 6.76	6.77 - 7.60	6.36 - 6.87	1.48 - 3.37	2.35 - 3.36

[1] None detected, < 0.2 mg/1

[2] None detected, < 0.012 mg/1

effect relationship between runoff and pH behavior in the river.

Table 4 presents the mean concentrations with 95% confidence limits for selected pollutants in the Allegheny River. These data show the extreme variability in the measurements made upstream and downstream. Generally, the upstream and downstream sites appear to have similar pollutant concentrations but a more detailed analysis was made using Student's 't' and the 'F' distribution tests.

Table 5 shows the results of the 't' and 'F' tests for comparisons of data from the upstream and downstream sites during dry and wet periods. There is no statistical difference between mean pollutant concentrations at the upstream and downstream sites during dry weather. The sample variances for TSS and Fe during the dry period at both sites were statistically different.

Table 6 shows the characteristics of the coal pile leachate during the dry weather sampling. The site layout with the drainage ditch and pipe facilitated the collection of leachate samples. These data show that the leachate is concentrated and extremely acidic. The leachate flow rate was very low and no effect on the river was detected. The total suspended and dissolved solids concentrations seem to be dependent upon the length of time since the previous rain. As this time increases, the concentrations decrease. The color of the leachate remained amber during the dry period.

Table 7 shows the rainfall event data collected at Warren, Pennsylvania. Other than suspended and dissolved solids, the pollutant concentrations were fairly consistent between the two storms. Since the first storm was a short-term, moderately intense cloudburst, it was not possible

TABLE 4

MEAN POLLUTANT CONCENTRATIONS WITH 95%
CONFIDENCE LIMITS IN THE ALLEGHENY RIVER AT
WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN PA
AUGUST - SEPTEMBER, 1976

Pollutant	POLLUTANT CONCENTRATION, mg/1			
	Upstream		Downstream	
	Dry	Wet	Dry	Wet
TSS	8.11 ± 2.26	7.25 ± 3.18	4.13 ± 2.04	5.50 ± 2.71
SO_4	13.89 ± 0.84	15.09 ± 0.94	13.83 ± 1.45	16.65 ± 2.25
Fe	0.23 ± 0.02	0.12 ± 0.03	0.21 ± 0.09	0.39 ± 0.27
Mn	0.028 ± 0.005	0.032 ± 0.003	0.023 ± 0.005	0.043 ± 0.012
Alk	41.65 ± 0.85	40.33 ± 0.94	39.33 ± 0.89	40.30 ± 0.34

95% confidence limits = $\bar{x} \pm t_{\nu,.025}\sqrt{\frac{s^2}{n}}$

TABLE 5

COMPARISONS OF MEAN VALUES & VARIANCES WITHIN 95% CONFIDENCE LIMITS AT UPSTREAM & DOWNSTREAM SITES DURING DRY & WET SAMPLING PERIODS
WARREN, PENNSYLVANIA
AUGUST - SEPTEMBER, 1976

Pollutant	Degrees of Freedom	t Test	Difference Between Means	Is Difference Between Means Significant?	Critical 'f' for 95% Confidence	'F' Ratio	Is Difference Between Variances Significant?
			UPSTREAM DRY - DOWNSTREAM DRY				
TSS	50	7.47	3.98	No	2.69	3.38	Yes Upstream > Downstream
SO_4	44	3.06	0.06	No	2.53	0.55	No
Fe	52	0.138	0.02	No	2.416	0.12	Yes Upstream < Downstream
Mn	51	0.015	0.005	No	2.422	2.00	No
Alk	65	2.59	2.32	No	2.173	1.72	No
			UPSTREAM WET - DOWNSTREAM WET				
TSS	16	8.45	1.75	No	4.82	1.88	No
SO_4	19	4.57	1.56	No	3.96	0.196	Yes Upstream < Downstream
Fe	17	0.495	0.27	No	4.36	0.011	Yes Upstream < Downstream
Mn	18	0.019	0.011	No	4.72	0.10	Yes Upstream < Downstream
Alk	17	1.86	0.03	No	4.10	6.52	Yes Upstream > Downstream
			UPSTREAM WET - UPSTREAM DRY				
TSS	45	9.26	0.86	No	2.50	0.43	No
SO_4	37	2.91	1.20	No	2.57	0.41	No
Fe	43	0.086	0.11	Yes	2.52	0.33	No
Mn	44	0.017	0.004	No	2.42	0.10	Yes Wet < Dry
Alk	50	3.81	1.32	No	2.44	0.20	Yes Wet < Dry
			DOWNSTREAM WET - DOWNSTREAM DRY				
TSS	21	6.71	1.37	No	3.38	0.77	No
SO_4	26	4.96	2.82	No	2.98	1.16	No
Fe	26	0.42	0.18	No	3.01	3.62	Yes Wet > Dry
Mn	25	0.0202	0.0200	Marginal	3.10	2.00	No
Alk	32	2.80	0.97	No	2.73	0.05	Yes Wet < Dry

TABLE 6

CHARACTERISTICS OF COAL PILE LEACHATE-DRY WEATHER
AT WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN, PA
AUGUST - SEPTEMBER, 1976

Date	Hours Since Last Rain	Pollutant Concentration, mg/1								Discharge Flow Rate lpm (gpm)
		TSS	TDS	SO_4	Fe	Al	Mn	Acidity	pH	
8/25/76	250	200	40,000	57,000	23,500	1,800	100	18,000	2.4	1.5 (.39)
8/27/76	17	18,700	82,600	45,000	14,000	1,400	70	27,000	2.1	1.5 (.39)
9/16/76	505	12	21,700	25,000	9,700	1,100	70	37,600	1.5	1.4 (.39)

TABLE 7

CHARACTERISTICS OF RAINFALL EVENTS
AT WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN, PA
AUGUST - SEPTEMBER, 1976

Site	Storm	Elapsed Time min	Total Precipitation mm (in)	POLLUTANT CONCENTRATION, mg/1						
				TSS	TDS	SO_4	Fe	Mn	Al	pH
Warren	1 8/26/76	20	2.8 (0.11)	0.9	1679.	14.9	21.5	0.275	3.18	3.90
	2 9/17/76	430	8.9 (0.35)	1.5	11.	12.4	19.8	0.304	2.71	4.15

to collect samples quickly enough to show any immediate effect of the runoff on the river. From this storm it was verified that the plug locations for sampling the surface runoff were adequate. The second storm lasted much longer and provided the bulk of data for evaluation and conclusions.

Table 8 presents the characteristics of the coal pile runoff and the surface runoff from the access road during the second storm event. At the start of the storm, the "first flush" effect with its higher pollutant concentrations can be seen. These values generally declined through the rainfall period. Some perturbations do appear since the rain did not fall at a constant rate throughout the day. All measured pollutant values are lower during rain than during dry periods. When a comparison of the data in Tables 6 and 8 is made, it appears that water stored in the coal pile solubilizes various impurities in the coal and leaks out very slowly. Rainfall washes out the stored water within the pile, thus greatly diluting the impurities.

A comparison of the coal pile runoff with the dry weather leachate, indicated that the rate of mass loadings of all pollutants on the river, except suspended solids, is greater during the dry period. A closer examination of this behavior is warranted.

The surface runoff shows much similarity with the coal pile runoff as the contaminant levels decreased through the storm's duration. Black granular material was observed on the access road and runoff surfaces during the field work, and the data indicate the presence of similar contaminants as in the coal pile runoff. The coal pile and surface runoff responded very quickly to rainfall intensity. The ground around the coal pile and the surface runoff areas had a very low porosity, practically

TABLE 8

CHARACTERISTICS OF COAL PILE & ACCESS ROAD RUNOFF
DURING SECOND STORM EVENT AT
WARREN STATION OF PENNSYLVANIA ELECTRIC CO., WARREN, PA
17 SEPTEMBER 1976

TIME	POLLUTANT (mg/1)														
	COAL PILE RUNOFF							DISCHARGE FLOW RATE	AVERAGE SURFACE RUNOFF						
	TSS	TDS	SO_4	FE	AL	MN	ACIDITY	lpm (gpm)	TSS	TDS	SO_4	FE	AL	MN	ACIDITY
1000 - 1015 - Rain Start	9800	4600	2300	900	100	40	3200	22 (5.8)	11200	2800	1000	100	100	10	1700
1015 - 1030	4200	3300	2300	-	-	-	2600		1400	900	600	200	40	5	600
1030 - 1045	6400	2400	1600	700	90	10	3100		4900	900	500	200	30	4	600
1045 - 1100	11400	2400	1800	1400	70	10	2000		4400	600	900	-	40	5	500
1100 - 1115	5000	2500	2100	700	80	10	2200	20 (5.3)	3700	500	400	300	50	5	300
1115 - 1130	1700	3700	2100	500	-	-	2900		3000	400	200	200	-	-	100
1130 - 1200	1400	3800	2700	-	-	-	-	20 (5.3)	1100	600	600	-	-	-	500
1200 - 1230	1600	3100	1700	300	-	-	-		3100	700	500	200	40	7	500
1230 - 1300	1700	3000	1000	200	-	-	-		1700	700	-	-	-	-	-
1300 - 1330	1700	-	-	-	-	-	-		1500	-	-	-	-	-	-
1330 - 1500 - Rain End	23000	500	200	-	-	2	500	17 (4.5)	2300	1400	1000	400	70	6	1000

zero. Within minutes after the rain stopped, the runoff declined to zero and the coal pile discharge returned to its prior appearance and flow rate.

The 't' and 'F' tests presented in Table 5 show no statistically significant effect of runoff on the river. However, in the case of sulfate, iron, manganese and alkalinity, the sample variances were significantly different. In the cases where differences were noted, except for total alkalinity, the upstream sample variance was lower than downstream. This difference is partly related to the sampling locations. Although both locations were as representative of the river's cross-section as could be determined, it is likely that the downstream site contained a greater number of anomalies. The river was very wide at this point with a greater probability for peculiarities in flow patterns due to the delta formation, rapids, and the large island just upstream of the site.

In a comparison of each river site during the wet and dry periods, the data show only two statistically significant differences. At the upstream site, the data indicate a difference in the mean concentration of iron. The dry period had much higher concentrations than the wet period. There was a marginal difference in manganese concentrations during wet and dry periods at the downstream site. A comparison of these 'wet' versus 'dry' variances with upstream versus downstream variances, indicates that they are partly the result of differences in the characteristics of each site as well as differences created by the rainfall events.

PORTLAND RESULTS

Table 9 shows the range of values for each pollutant at the Portland Station sampling sites. These ranges are similar to those measured at the Warren Station sites. They commonly vary by up to an order of magnitude.

The pH values during the short sampling period at Portland appear to cover a higher range downstream from the plant, contrary to pH values observed at Warren.

Table 10 shows the 95% confidence limits for the upstream and downstream sites during dry and wet periods. As was true with the Warren sampling data, most of the Portland data at each river sampling site seems to be similar during both the 'dry' and 'wet' sampling periods. A comparison of Portland data with Warren data indicates that the Delaware River at Portland has higher suspended solids, iron and manganese, but lower alkalinity and similar sulfate concentrations.

Student's 't' and 'F' distribution tests of significance were performed to establish any apparent relationships between sites and sampling locations (see Table 11). As expected, the 't' and 'F' tests on the dry weather data show no significant differences between means or variances at upstream and downstream sites. The sample variances at Portland were noticeably greater than at Warren, due possibly to the smaller sample size at Portland. The intrinsic characteristics of each river's behavior, as well as the sampling techniques used, are also undefined contributors to the sample variance.

The parameters associated with the single rain event at Portland are presented in Table 12. The rain at Portland had noticeably lower con-

TABLE 9

RANGE OF POLLUTANT CONCENTRATION AT THE SAMPLING LOCATIONS AT PORTLAND STATION OF METROPOLITAN EDISON CO., PORTLAND, PA
OCTOBER 1976

Pollutant	RANGE OF POLLUTANT CONCENTRATION, mg/1							
	Upstream		Downstream		Coal Pile Runoff		Fly Ash Pile Runoff	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Total Suspended Solids	3 - 33	10 - 20	2 - 43	4 - 11	-	220 - 3800	-	840 -15200
Total Dissolved Solids	43 - 72	62 - 89	38 - 71	46 - 67	-	600 - 7500	-	730 - 2500
Iron	.18 - 2.0	.18 - .45	.18 - 1.4	.18 - .63	-	18 - 400	-	73 - 245
Aluminum	N.D.[1] - .63	N.D.[1]	N.D.[1] - 1.25	N.D.[1]	-	2.75 - 88	-	63 - 200
Manganese	.03 - .14	N.D.[2] -.03	.01 - .18	N.D.- .03	-	3.75	-	.03 - 25
Sulfate	10 - 18	9 - 22	5 - 12	5 - 11	-	380 - 6000	-	100 - 1600
Total Alkalinity @ $CaCO_3$	12 - 25	16 - 19	12 - 21	16 - 20	-	-	-	-
Total Acidity @ $CaCO_3$	-	-	-	-	-	300 - 4600	-	11 - 800
pH	6.2 - 6.8	6.5 - 6.8	6.3 - 7.2	6.6 - 7.2	-	2.35 - 3.10	-	2.72 - 3.06

[1] None detected, < 0.2 mg/1

[2] None detected, < 0.012 mg/1

TABLE 10

MEAN CONCENTRATIONS WITH 95% CONFIDENCE LIMITS FOR SELECTED POLLUTANTS AT THE PORTLAND STATION OF METROPOLITAN EDISON CO., PORTLAND, PA OCTOBER 1976

	POLLUTANT CONCENTRATION, mg/1			
	Upstream		Downstream	
Pollutant	Dry	Wet	Dry	Wet
TSS	12.72 ± 4.86	13.54 ± 5.91	11.66 ± 6.96	7.39 ± 2.20
SO_4	12.86 ± 1.31	14.25 ± 6.12	10.10 ± 1.10	8.15 ± 1.31
Fe	0.56 ± 0.22	0.30 ± 0.10	0.56 ± 0.18	0.43 ± 0.21
Mn	0.051 ± 0.016	0.020 ± 0.010	0.055 ± 0.020	0.016 ± 0.006
Alk	16.07 ± 1.82	17.60 ± 1.42	15.59 ± 1.26	16.38 ± 0.43

TABLE 11

COMPARISONS OF MEAN VALUES & VARIANCES WITHIN 95% CONFIDENCE LIMITS AT UPSTREAM & DOWNSTREAM SITES DURING DRY & WET SAMPLING PERIODS PORTLAND STATION

Pollutant	Degrees of Freedom	t Test	Difference Between Means	Is Difference Between Means Significant?	Critical 'f' for 95% Confidence	'F' Ratio	Is Difference Between Variances Significant?	
UPSTREAM DRY - DOWNSTREAM DRY								
TSS	27	17.48	1.06	No	2.96	0.378	No	
SO_4	35	3.32	2.76	No	2.62	1.18	No	
Fe	37	0.55	0	No	2.53	1.21	No	
Mn	36	0.05	0.004	No	2.55	0.50	No	
Alk	29	4.20	0.48	No	2.86	1.65	No	
UPSTREAM WET - DOWNSTREAM WET								
TSS	11	9.82	6.15	No	5.52	3.26	No	
SO_4	16	7.34	6.10	No	4.12	5.16	Yes	Upstream > Downstream
Fe	16	0.631	0.13	No	4.04	0.091	Yes	Upstream < Downstream
Mn	16	0.044	0.004	No	4.04	1.00	No	
Alk	11	2.22	1.22	No	5.52	4.81	No	
UPSTREAM WET - UPSTREAM DRY								
TSS	16	17.40	0.82	No	4.12	0.350	No	
SO_4	20	7.02	1.39	No	3.73	3.76	Marginal	Dry < Wet
Fe	22	0.791	0.26	No	3.44	0.052	Yes	Dry > Wet
Mn	21	0.058	0.031	No	3.50	0.100	Yes	Dry < Wet
Alk	17	6.52	1.53	No	4.00	0.131	No	
DOWNSTREAM WET - DOWNSTREAM DRY								
TSS	22	20.29	4.27	No	3.29	0.041	Yes	Dry > Wet
SO_4	31	3.38	1.95	No	2.72	0.861	No	
Fe	31	0.568	0.13	No	2.73	0.688	No	
Mn	31	0.055	0.039	No	2.73	0.05	Yes	Dry > Wet
Alk	23	3.79	0.79	No	3.22	0.045	Yes	Dry > Wet

TABLE 12

CHARACTERISTICS OF THE RAINFALL EVENT AT PORTLAND STATION OF METROPOLITAN EDISON CO., PORTLAND, PA
20 OCTOBER 1976

Site	Storm	Elapsed Time min	Total Precipitation mm (in)	POLLUTANT CONCENTRATION, mg/1						
				TSS	TDS	SO_4	Fe	Mn	Al	pH
Portland	10/20/76	810	3.92 (1.55)	2.	102	9.7	0.18	ND[1]	ND[2]	5.70

[1] None Detected, < 0.012 mg/1
[2] None Detected, < 0.2 mg/1

centrations of iron, manganese and aluminum than at Warren. Other parameters were similar between the two sites.

When compared with the Warren data, the coal pile runoff has substantially lower concentrations of pollutants (see Table 13). In part, this is the result of the different sampling procedures required at each site as determined by the site layout. At Warren, the entire runoff from the coal pile was intercepted by a drainage ditch. At Portland, only a small portion of the total runoff was captured from a coal pile that was much farther from the sampling location. Collection of samples had to be made near the surface drain since the terrain near the pile was uncertain and the survey objective was to examine only the portion draining to the river. It is also possible that the distance between the coal pile and the surface drain allowed the soil to filter pollutants out of the runoff.

Compared with Warren, the response of runoff flow at Portland was much slower (i.e., there was a greater time lag) with respect to the rainfall intensity. The runoff did have sufficient force to transport quite large (1-5 mm) particles. Plug sampling replaced automatic sampling after the sequential samplers became inoperative from being jammed with these particles. The plug collectors, even with screen covers, did collect some of the push-along particles that the sequential sampler did not. This could explain the change of pollutant concentrations at 1000 hours. The large particles were removed from the sample within a few hours prior to returning the samples for analysis, but their partial dissolution could explain the increase in concentrations. There is also the possibility that rainfall intensities, with their effect of washing out more of the

TABLE 13

CHARACTERISTICS OF COAL PILE & FLY ASH AREA RUNOFF DURING THE RAINFALL EVENT AT PORTLAND STATION OF METROPOLITAN EDISON CO., PORTLAND, PA

20 OCTOBER 1976

TIME	POLLUTANT (mg/1)													
	COAL PILE RUNOFF							FLY ASH AREA RUNOFF						
	TSS	TDS	SO_4	FE[1]	AL[1]	MN[1]	ACIDITY	TSS	TDS	SO_4	FE	AL	MN	ACIDITY
0700 - 0730	240	-	-	20	8	0.4	290	200	200	100		-	-	10
0730 - 0800	300	-	-	40	19	0.8	300	400	400	200	-	-	-	200
0800 - 0830	350	500	500	-	-	-	-	-	-	-	-	-	-	-
0830 - 0900	-	600	500	60	15	0.6	370	-	-	-	-	-	-	-
0900 - 1000	230	600	400	80	15	0.5	300	800	1300	-	-	-	-	400
1000 - 1100	280	3400	2000	400	50	1.8	2400	1200	1700	1100	100	60	2.3	700
1100 - 1200	-	-	-	-	-	-	-	6600	2200	1400	200	140	1.3	900
1200 - 1300	-	-	-	-	-	-	-	-	-	-	-	-	-	
1300 - 1400	1700	4200	-	300	30	1.6	-	-	-	-	-	-	-	
1400 - 1500	2200	7500	6000	-	-	-	4600	14000	1800	1200	200	200	0.2	500
1500 - 1700	2200	4800	-	200	50	2.5	-	2300	1000	800	150	60	1.2	600
1700 - 1830	3800	4300	2600	400	90	2.5	2600	1200	800	700	-	-	-	500

[1] Concentrations as entering the river

soluble material, could have caused this increase. The fly ash pile area released much higher concentrations of suspended and dissolved solids into the river than the coal pile runoff released. Acidity, sulfate, and metals concentrations were lower. The flow from the coal pile and the fly ash storage area could not be quantified with any success. If the study had continued for another rain event, semi-permanent weirs would have been installed to eliminate this problem.

As indicated in Table 11, the runoff from the coal pile and fly ash area did not have any measurable effect on the river. Statistically, there was no measured difference at either site during the wet and dry sampling periods. These observations must be mitigated by the small sample size as well as statistically significant differences in the sample variances.

The sample variances at Portland, except for dry weather comparisons, are statistically different for each of the compared sample sets. There is no apparent consistency to these differences with respect to pollutant, site, or sampling condition. It can be concluded that a rain event does introduce an additional degree of variability to the data. The Portland 'dry' data shows no difference in variance between samples taken at the two sampling sites. This contrasts with the Warren 'dry' data which did have some variances. The sampling location is another factor affecting the Warren data but not the Portland data, where the river flow pattern was less complex. The sample variances are similar at Warren and Portland for each pollutant with few exceptions, despite the slight differences in sample size. Total suspended solids and iron seem to have the greatest degree of variation at both sites under the different sampling conditions.

CONCLUSIONS

The following conclusions resulted from the field survey:

1. The pollutant concentrations in the river at both sites were highly variable, often by an order of magnitude. These variations were independent of river flow and weather conditions.

2. The mass loadings of pollutants in the Delaware River increased substantially during and after the sampled storm event. This was due primarily to an increased flow attributable to upstream conditions and storm intensity. The mass loading of pollutants in the Allegheny River remained essentially unchanged for both sampled storm events since river flow was controlled by a dam approximately six miles upstream and neither storm event was substantial. Therefore, the pollutant concentrations in each river at both upstream and downstream sampling stations were not necessarily higher during storm conditions.

3. The data from these two sites generally show no statistical difference in mean concentrations of upstream versus downstream pollutant levels in either dry or wet conditions.

4. The data show no statistical difference in sample variances which are not consistently predictable with respect to pollutant, site, and sampling period.

5. The main contributors to the change in S^2 of the calculated variance were site location and the storm event. The site location was the major contributor at Warren, while the rain event was the major contributor at Portland. The sample variances were generally consistent for each pollutant at the Warren and Portland sites. The only exceptions were total suspended solids and iron.

6. The storm data from Warren show a "first flush" effect from the initial runoff of the access road which contained fugitive fallout from the coal pile and coal trucks.

7. The pollutant concentrations of the leachates from the coal pile at Warren were orders of magnitude higher than the storm runoff pollutant concentrations. For a short duration, moderate intensity storm and a moderate duration low intensity storm (the two events sampled at Warren), the leachate mass loading was greater than the storm mass loading because the leachate drained for several days. Thus, for the two storms sampled at Warren, the pollutant loads on the river from the utility were less during rain than during dry weather with the exception of total suspended solids.

8. The sample plugs worked effectively except for one problem; soluble solids slipped through the screen prior to runoff and leached into the sample, creating higher measured pollutant concentrations.

The Warren and Portland station data do not show any coal pile runoff impact on the river. It appears sample sizes may be too small (due to lack of rain) to indicate a definitive conclusion of the runoff effects at either Warren or Portland. The data certainly can be improved with a larger data base (more rain events) and some improvement in sample variances. This program points out the inherent problem of sampling runoff; i.e., the need of representative storm events. A field program of this nature can be costly if it does not rain. Even if it rains, a sampled event must be related to other cases of rainfall duration and intensity and to antecedent dry days before the storm. It is these problems which make the use of a mathematical model to predict runoff and its impact on receiving waters so valuable. Therefore, before regulations can be generated for industrial stormwater runoff, more problem definition (sampling and modeling) must be performed.

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THE DEVELOPMENT OF A MATHEMATICAL MODEL TO SIMULATE INDUSTRIAL NON-POINT SOURCE POLLUTION

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ABSTRACT

Non-point source pollution is presently a significant concern to those responsible for maintaining and improving water quality. Although non-point source pollution has been studied in some detail for urban environments, industrial non-point source pollution, a potentially critical problem area, has not received much attention.

The U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina, has retained TRC - The Research Corporation of New England to identify non-point source pollution from twelve industries, and to quantify and qualify non-point source pollution from the coal-fired utility and iron and steel industries. Recognizing that it is extremely costly to conduct extensive field measurement programs on a site-by-site basis, the USEPA asked TRC to develop and apply a mathematical model (in conjunction with a field measurement program) capable of simulating both the quantity and quality of industrial non-point source pollution and its impact on receiving waters.

The TRC-developed model was applied at two coal-fired utility plants to simulate non-point source pollution resulting from stormwater runoff from coal storage areas and from plant areas covered with dust fallout from coal handling and ash handling operations. When compared to field measurements, the modeled results compared within a factor of 4 for both the quantity and quality of stormwater runoff and its impact on the water quality of the receiving waters. These results indicate that the model

can be used with a minimum of field data to successfully simulate industrial non-point source pollution and its impact on receiving waters for the utility industry. In addition, due to inherent flexibility, the TRC model can serve as a useful, cost-effective tool to evaluate non-point source pollution from other industries.

A description of the TRC model development program and its results are presented in this paper.

1.0 INTRODUCTION

Non-point source pollution is presently a significant cause of concern to those responsible for maintaining and improving water quality. Although non-point source pollution has been studied in some detail for urban environments, industrial non-point source pollution, a potentially critical problem area, has not received much attention.

The U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory at Research Triangle Park, North Carolina, has retained TRC - The Research Corporation of New England to identify non-point source pollution from twelve industries and to quantify and qualify non-point source pollution from two of these industries: coal-fired utility and iron and steel. Recognizing that it is extremely costly to conduct extensive field measurement programs on a site-by-site basis, the USEPA asked TRC to develop and apply a mathematical model capable of simulating both the quantity and quality of industrial non-point source pollution and its impact on receiving waters. The TRC-developed model was applied at two coal-fired utility stations and evaluated in conjunction with field measurements made at these stations.

A description of the TRC model development program, including model selection, application, and evaluation, is presented herein.

2.0 MODEL SELECTION

Prior to the work described in this paper, little had been done to develop a mathematical model to quantify and qualify industrial non-point source pollution and its impact on receiving waters for specific industries, with the exception of agriculture and mining. The objective of this program was to develop such a mathematical model capable of quantifying and qualifying non-point source industrial loadings associated with stormwater runoff - the predominant mechanism for non-point source pollution - and the impact of such runoff on receiving waters. To increase model utilization, the model was to be inherently flexible so that it could be applied to various types of industry with only minor modifications.

To effectively satisfy the above objective, existing mathematical models were reviewed and the model best able to meet the study objective was chosen for development and adaptation.

Ten models were selected for review. A comparison of model capabilities, application, complexity, cost, and availability is presented in Table 1.

Of the ten models reviewed, the simplest, most flexible model requiring the least amount of modification with the capability to quantify and qualify stormwater runoff from industry and to determine the impact of such runoff on receiving waters was the Short Stormwater Management Model and Receiv II (SSWMM-RECEIV II).

The Short Stormwater Management Model (SSWMM) and Receiv II (RECEIV II) are both modified versions of the EPA-SWMM model. SSWMM, developed by the University City Science Center in 1976, is a simplified version of

TABLE 1

A COMPARISON OF MODEL CAPABILITIES, APPLICATION, COMPLEXITY, COST, AND AVAILABILITY

Model Identification		Model Capabilities																						Potential Model Application					Program Modification Required	Relative Model Complexity	Relative Model Cost	Computer Program Available
Name	Date Released	Wastewater				Receiving Water					Quality Parameters											Simulation of Single Storm	Simulation of Multiple Storm	Agriculture	Mining	Construction	Energy	Other Industries*				
		Quantity	Quality	Dry Weather Flows	Storm Runoff	Quantity	Quality	River	Lake	Estuary	Temperature	Suspended Solids	Total Dissolved solids	BOD5	COD	Dissolved Oxygen	Nitrogen	Phosphorous	pH	Oil and Grease	Pesticides											
EPA SWMM Release II 1	1974	X	X	X	X	X	X	X	X	X		X		X	W	X	W	W		W		X	X	X	X	X	X	X	X	H	H	X
WRE Stormwater Management Model 2	1973	X	X	X	X	X	X	X	X	X		X		X			X	X		X		X		X	X	X	X	X	X	H	H	P
SSWMM/ 3 RECEIV II 4	1976 1974	X	X	X	X	X	X	X	X	X		X		X		X	X	X				X	X	X	X	X	X	X	X	M	M	P/X
Hydrocomp Simulation Program 5	1974	X	X	X	X	X	X	X	X		X		X	X		X	X	X	X				X	X	X	X	X	X	X	H	H	P
Dorsch Consult 6	1975	X	X	X	X	X	X	X	X	X				X	D		D	D				X	X	X	X	X	X	X	X	H	H	P
Corps. of Engineers STORM 7	1975	X	X		X	D	D	D	D	D		W		W			W	W				X	X	X	X	X	X	X	X	M	M	X
Battelle Waste-Water Management Model 8	1976	X	X	X	X							W		W	W		W	W				X		X	X	X	X	X	X	M	M	X
Metcalf&Eddy Simplified Stormwater Management Model 9	1976	X	X	X	X							W		W			W	W					X	X	X	X	X	X	X	L	L	X
EPA-Hydrocomp ARM 10	1976	X	X	X	X							W					W	W			W	X	X	X						M	M	X
Pyritic Systems: A Mathematical Model 11	1972	X	X	X	X						H_2SO_4 - Only												X		X				X	M	M	X

*Cement, feedlots; inorganic chemicals; fertilizer manufacturing; petroleum refining; iron and steel; non-ferrous metals; phosphate manufacturing; timber.

- Key -

X = Yes	H = Complex/costly
W = Wastewater only	M = Moderately complex/moderately costly
D = Currently being developed	L = Simple/low cost
P = Proprietary	

the runoff portion of the EPA-SWMM model, and RECEIV II, developed by the Raytheon Company for the EPA in 1974, is a modified version of the receiving water portion of the EPA-SWMM model. When combined, SSWMM and RECEIV II are capable of dynamically simulating both the quantity and quality of stormwater runoff and the impact of such runoff on the quantity and quality of receiving waters, including rivers, lakes, and estuaries. The user can define, with certain restrictions, the quality parameters which he chooses to simulate. Pollutant transport can be modeled by both overland flow and sewer routing. Dry weather flows can also be simulated. The model is primarily designed to simulate individual storm events but can be used to model multiple storm periods.

Potential model application for both runoff and receiving water simulation includes all industry categories identified in Table 1; however, model development and modification is required for any such application.

3.0 MODEL DEVELOPMENT

Model development is described in terms of the model development tasks, a description of SSWMM-RECEIV II as developed by TRC, and model utilization.

3.1 Model Development Tasks

To meet the program objectives, it was necessary to both modify and interface SSWMM and RECEIV II. Specifically, TRC:

- Modified the stormwater runoff quality relationship in SSWMM to make the model more suitable for industrial application.
- Modified RECEIV II to increase the model's sensitivity in the receiving water to a specific plant's point and non-point discharges.
- Created a program to combine SSWMM and RECEIV II.

3.2 Description of SSWMM-RECEIV II

3.2.1 General Description

The SSWMM-RECEIV II model as developed by TRC[12] consists of four programs:

SSWMM (Short Stormwater Management Model Program)
LNKPRG (Link Program)
SETUP/QUANTITY (RECEIV II Quantity Program)
QUALITY (RECEIV II Quality Program)

SSWMM simulates both the quantity and quality of stormwater runoff. LNKPRG interfaces SSWMM and RECEIV II (SETUP/QUANTITY and QUALITY). RECEIV II SETUP/QUANTITY simulates hydraulics in the receiving water and the impact of the stormwater runoff on these hydraulics. RECEIV II QUALITY simulates water quality in the receiving water and the impact of the stormwater runoff on the quality of the receiving water. A flowchart for SSWMM-RECEIV II is presented in Figure 1.

SSWMM-RECEIV II is written in Fortran IV and was developed for installation on a Univac 90/30 digital computer with a basic compiler (equivalent to an IBM 370 Level G Compiler). The program requires 100K bytes of core storage.

3.2.2 Input Information Requirements

Model input information requirements are fairly extensive and best described in terms of the individual program requirements for SSWMM, LNKPRG, SETUP/QUANTITY and QUALITY.

SSWMM Input

SSWMM input includes information such as physical descriptions of user-selected simulation elements, storm activity, and pollutant generation and washoff data.

As initial steps in preparing input information, the user must divide the land area to be modeled into discrete spatial elements representative of drainage patterns and land use characteristics, and must choose the temporal framework for model computation. The discrete elements can be either subcatchments (drainage areas within a watershed with overland flow) or gutters (drainage ditches, pipes, manholes, and inlets; i.e., points of runoff entry to receiving waters). Information necessary to establish this spatial framework is normally available from plant engineering drawings. The temporal framework (computational timestep length) for SSWMM should be chosen to reflect storm activity and the user's needs.

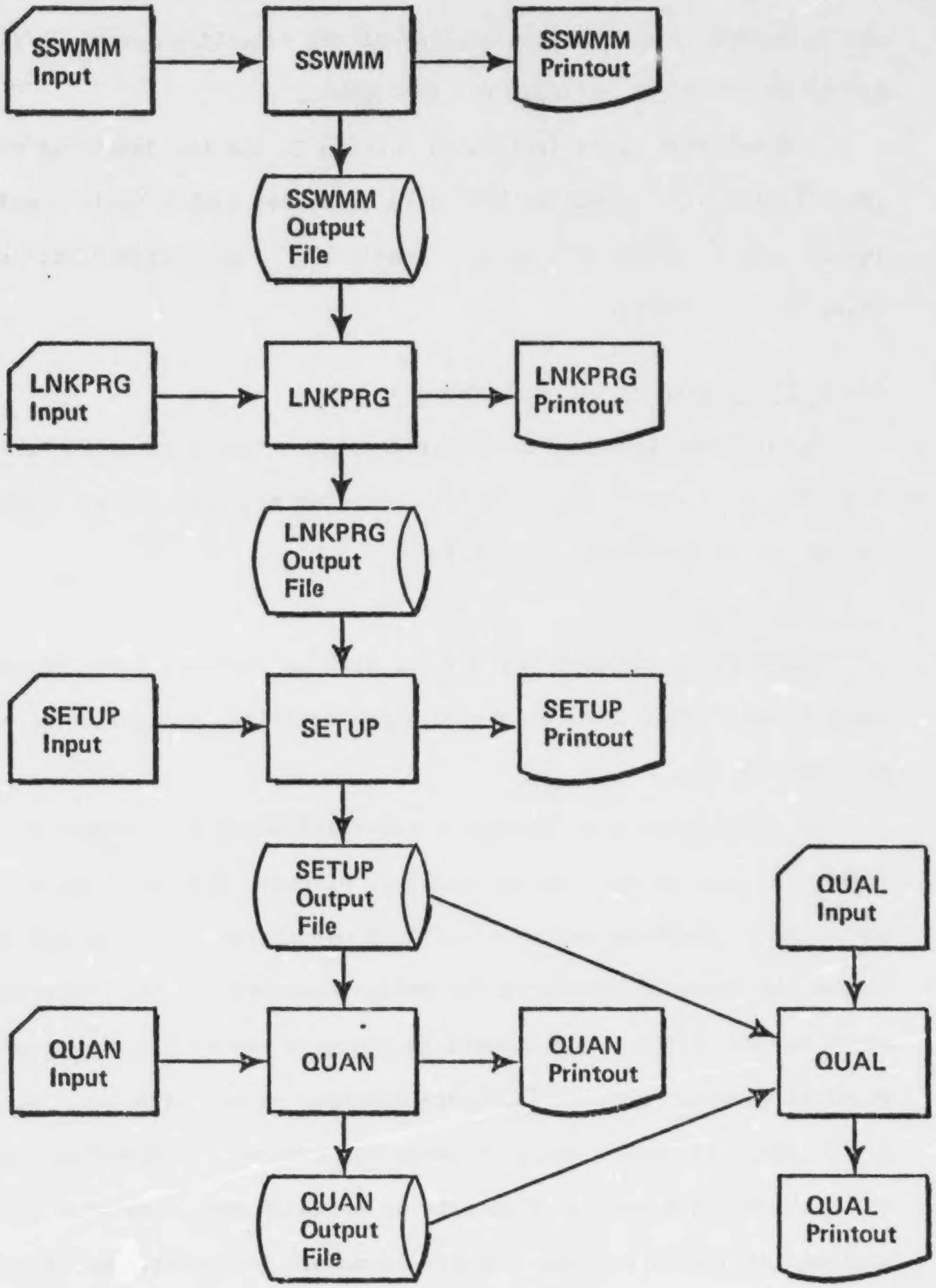
SSWMM Input
SSWMM
SSWMM Printout
SSWMM Output File
LNKPRG Input
LNKPRG
LNKPRG Printout
LNKPRG Output File
SETUP Input
SETUP
SETUP Printout
SETUP Output File
QUAL Input
QUAN Input
QUAN
QUAN Printout
QUAL
QUAN Output File
QUAL Printout

Fig. 1
SSWMM - RECEIV II Flowchart

Information necessary relative to storm activity includes rainfall intensity, storm duration, and the number of days between storms. This data may be obtained from a local National Weather Service meteorological station or from rainfall data gathered by plant personnel. If neither source is available, a rain gauge must be installed to measure rainfall intensity at the plant.

Information model requirements for pollutant generation and washoff data are critical. The amount of pollutant washed from the land surface during a storm is, in part, related to the initial (pre-storm) mass of pollutant on the land surface. The initial pollutant mass load is equal to the dust and dirt accumulation rate multiplied by the area of the watershed with that dust and dirt accumulation rate, the number of dry days between storms, and the amount of a particular pollutant in the dust and dirt. The dust and dirt accumulation rate and the amount of a particular pollutant in the dust and dirt can be determined by field measurement and laboratory analysis, or from information available in the literature. For most industrial sites, very little pollutant generation data is available in the literature, and it is necessary to conduct a field measurement and laboratory analysis program. The area of the watershed with the dust and dirt accumulation rate and the number of dry days between storms are determined from the physical descriptions of the simulation elements and from storm activity records.

LNKPRG Input

LNKPRG input includes the information output file from SSWMM and an input card deck. The card input consists of user-determined program interface instructions to link SSWMM and RECEIV II (SETUP/QUANTITY, QUALITY) and non-storm inputs to or withdrawals from the receiving water (background receiving water flows and pollutant mass loads, industrial process and cooling water flows and pollutant mass loads, etc.). Information on non-storm inputs can be gathered from plant personnel and from government groups such as the United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the U.S. Army Corps of Engineers.

SETUP/QUANTITY Input

Input requirements for the SETUP/QUANTITY portion of RECEIV II include the information output file from LNKPRG and two input card decks. The input card decks include geographical, hydraulic, and meteorological data describing the receiving water.

As with SSWMM, in SETUP/QUANTITY the user must first divide the receiving water to be modeled into discrete elements representative of the waterway's hydrology and characteristic uses (industrial withdrawals and discharges, etc.), and choose, with certain restrictions, the temporal framework for model computation. The discrete elements include nodes or junctions (sections of the receiving water with uniform hydraulic and water quality properties) and channels linking the nodes. Information necessary to establish this spatial framework is normally available from National Ocean Survey bathymetric charts, USGS 7.5' topographic maps, and U.S. Army Corps of Engineers flood studies. More specific spatial information might be available from plant personnel if they had conducted any studies on the receiving water adjacent to the plant. The temporal framework (computational timestep length) for SETUP/QUANTITY should be chosen to reflect the user's needs, but must meet certain restrictive requirements determined by the choice of the spatial framework.

In addition to this geographical and hydrological information, meteorological information, including rates of rainfall and evaporation which influence the volume and flow of water in the receiving water, can be input to SETUP/QUANTITY. If required, this information is normally available through the National Weather Service.

QUALITY Input

The QUALITY information requirements include the information output file from SETUP/QUANTITY and a card deck input. The card deck input includes information describing the initial pollutant concentrations in the receiving water and pollutant reaction kinetics (reaction rates, water temperatures, and temperature compensation coefficients). Values for initial pollutant concentrations in the receiving water can be determined from the USGS or NOAA, but more specific information might be available from plant personnel. Information on pollutant reaction kinetics is often available in the literature. If this information is not adequate, a field measurement program may be conducted to determine reaction kinetics; however, this is often costly.

3.2.3 Output Information

Model results are printed for each of the programs (SSWMM, LNKPRG, SETUP/QUANTITY, QUALITY) in the SSWMM-RECEIV II model.

Results from SSWMM include:

- Initial pollutant loads (mg) on each subcatchment prior to the storm.
- Stormwater flow (cfs) and associated pollutant mass loads (lbs./min.) for each timestep.
- Total amount of rainfall (cu. ft.), total infiltration (cu. ft.), total runoff (cu. ft.), total surface storage (cu. ft.), and the percentage error computed for unaccounted water.
- Total pollutant mass (lbs.) washed from the land surface during the storm.

LNKPRG results include the stormwater flows and pollutant mass loads from SSWMM converted to a format acceptable to RECEIV II (SETUP/QUANTITY, QUALITY).

Results from SETUP/QUANTITY include:

- Hydraulic head (m) or water level in the receiving water at each node for each timestep.
- Water flow (m^3/sec) and velocity (m/sec) in the receiving water in each channel for each timestep.

Results from QUALITY include:

- Pollutant concentrations (mg/l) in the receiving water at each node for each timestep.
- Daily maximum, minimum, and average pollutant concentrations (mg/l) in the receiving water at each node.

3.3 Model Utilization

SSWMM-RECEIV II can be used to effectively simulate industrial non-point source pollution associated with stormwater runoff from material storage piles and from areas of dust and dirt accumulation without performing a detailed field measurement program. The model can also be used to simulate the subsequent impact of this runoff on receiving waters (rivers, lakes, or estuaries). Pollutants that can be modeled are user-selected and include items such as solids, nutrients, and metals.

Typical model applications for new or existing plants might include:

- Defining industrial stormwater runoff flow and pollutant concentrations.
- Defining the impact (flow and pollutant concentration changes in the receiving water) resulting from the stormwater runoff.
- Defining design criteria for stormwater treatment.
- Evaluating stormwater treatment alternatives.

In addition to the industrial uses cited above, SSWMM-RECEIV II can be used with minor modification to simulate non-point source pollution associated with stormwater runoff for urban and rural environments. This information can be used in river basin planning or 208 planning activities.

As with any mathematical model, care must be taken to apply SSWMM-RECEIV II correctly. The user must understand and work within the model limitations. At this time SSWMM-RECEIV II:

- Cannot simulate stormwater percolation through or the erosion of material storage piles, but can simulate stormwater runoff from material storage piles.
- Has not been tested to simulate dynamic background source flows and loadings in the receiving water.
- Must be used within temporal and spatial limits defined in the model.

4.0 MODEL APPLICATION

To test the validity of SSWMM-RECEIV II, the model was used to simulate storm-induced, non-point source pollution and the impact of such pollution on receiving waters at two coal-fired utility plants. The results were compared to field measured data. The two plants were the Warren Generating Station (Pennsylvania Electric Company) on the Allegheny River in Warren, Pennsylvania, and the Portland Generating Station (Metropolitan Edison Company) on the Delaware River in Portland, Pennsylvania. Table 2 summarizes the plant characteristics. The pollutants modeled included total suspended solids, total dissolved silids, sulfates, total iron, manganese, and aluminum.

The model test inputs and the comparison of the modeled and measured field data are discussed in Sections 4.1 and 4.2.

4.1 Model Test Inputs

As discussed previously, model inputs to SSWMM-RECEIV II include land and receiving water discretization information, pollutant generation activity on land, storm activity, and background flow and pollutant loadings in the receiving waters.

As depicted in Figure 2, the land area at Warren was divided into three watersheds based on drainage patterns and land use. These watersheds are represented by Elements 1, 4, and 6. The discharge point of drainage from each of the three watersheds to the river is classified as an inlet. These inlets are labeled as Elements 3, 5, and 8. The first watershed (Element 1) represents the coal pile drainage area. The runoff from this area enters a culvert (Element 2) which empties into the Allegheny River

TABLE 2

CHARACTERISTICS OF THE SAMPLING SITES USED IN THE SURVEY

Utility	Pennsylvania Electric Co.	Metropolitan Edison
Plant	Warren Station	Portland Station
Location	Warren, PA	Portland, PA
Capacity Mw output, net	84	410
Coal Characteristics		
Usage (metric tons/yr)	315,000 est. 1974	840,000 est. 1974
Source	Clarion Co., PA	PA & W. VA
Storage, metric tons	27,200	172,000
Sulfur %	1.84	1.47
Iron %	0.35	0.38
Manganese %	0.003	0.004
Aluminum %	0.56	0.37
Coal Delivery	Truck	Railroad Car

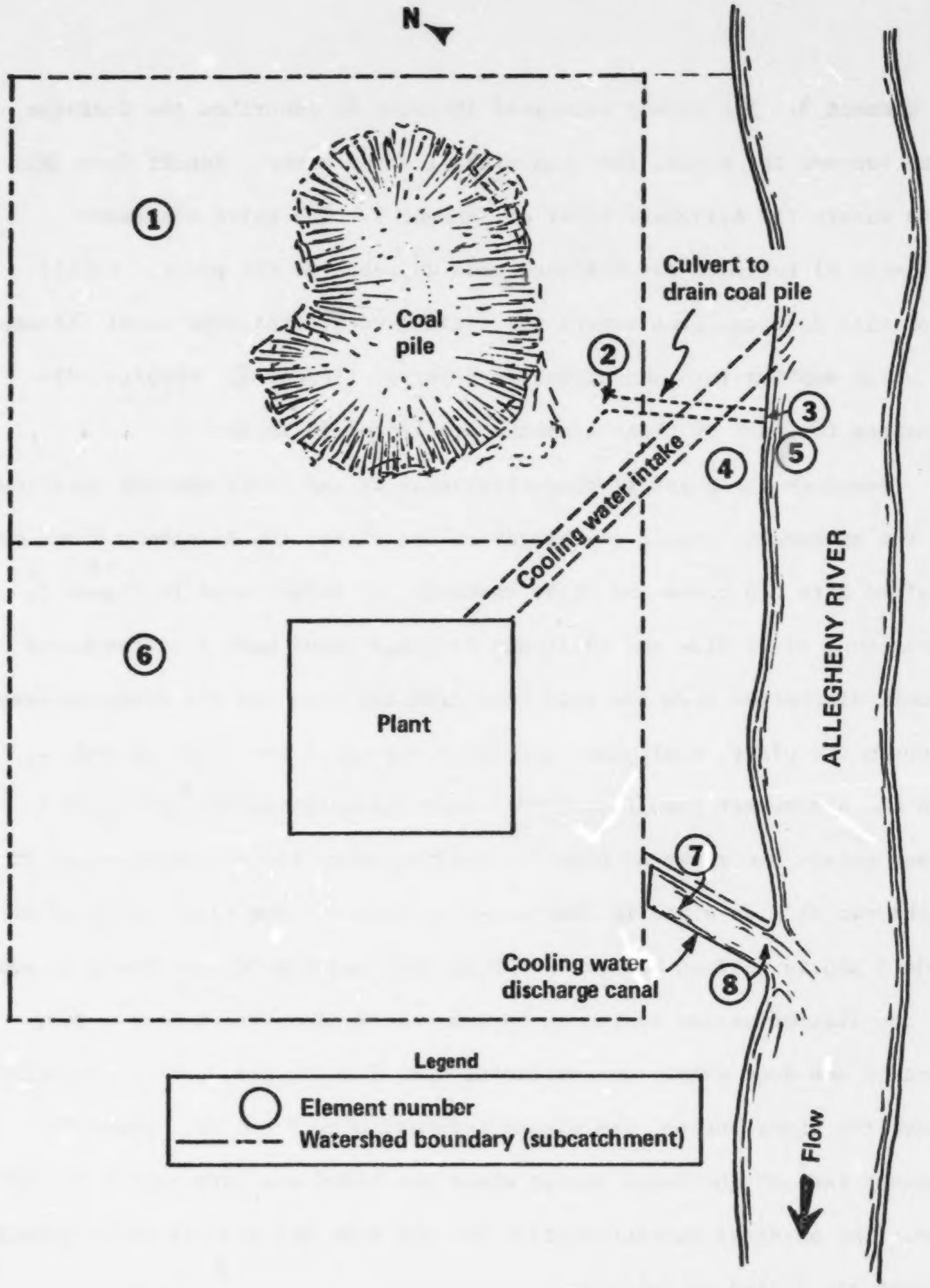
N
①
Coal pile
Culvert to drain coal pile
②
③
④
⑤
Cooling water intake
⑥
Plant
ALLEGHENY RIVER
⑦
Cooling water discharge canal
⑧
Flow
Legend
○ Element number
— - — Watershed boundary (subcatchment)

Fig. 2
Discretization scheme schematic
of land area; Warren, PA.

at Element 3. The second watershed (Element 4) describes the drainage area between the plant, the coal pile, and the river. Runoff from this area enters the Allegheny River at Element 5. The third watershed (Element 6) includes the drainage area adjacent to the plant. Runoff from this drainage area enters the cooling water discharge canal (Element 7) which empties into the Allegheny River at Element 8. Physical dimensions for each of these elements are listed in Table 3.

Based on the physical characteristics of the river and the location of the stormwater runoff discharges to the river, the Allegheny River was divided into ten nodes and eight channels, as illustrated in Figure 3. Background river flow and pollutant loadings enter node 1. Stormwater runoff discharges from the coal pile drainage area and the drainage area between the plant, coal pile, and the river enter the river at node 4, and the stormwater runoff discharge from the drainage area adjacent to the plant enters the river at node 5. Cooling water for the power plant is withdrawn at node 4 and is discharged at node 5. The river branches at node 5 and is unified at node 9. Since the model requires the last node in the discretization system to be immediately downstream from a dam, even if one does exist, an artificial dam, i.e., a dam with no elevation above the river bottom, was placed between nodes 9 and 10. Channels connect each of the nodes except where the nodes are interrupted by the dam. The physical characteristics for the node and channel discretization scheme are listed in Table 4.

Based on drainage patterns and land use, the land area at Portland was divided into four watersheds, labeled as Elements 1, 3, 5, and 8, in

TABLE 3

DISCRETIZATION: LAND ELEMENTS
WARREN, PA

Element No.	Type[1]	Width (ft)	Slope (ft/ft)	AR OR GL[2]	PI OR DF[2]
1	1	338.00	0.0180	2.61	100.00
2	2	1.00	0.1370	153.13	0.95
3	2	0.00	0.0000	0.00	0.00
4	1	488.00	0.1370	1.71	100.00
5	2	0.00	0.0000	0.00	0.00
6	1	275.00	0.0450	2.53	100.00
7	2	25.00	0.0220	325.00	23.75
8	2	0.00	0.0000	0.00	0.00

[1] Type 1 is a watershed
Type 2 is a pipe or manhole

[2] AR = Area of watershed (AC); PI = Percent imperviousness (%)
GL = Pipe length (Ft) ; DF = .95 * Width

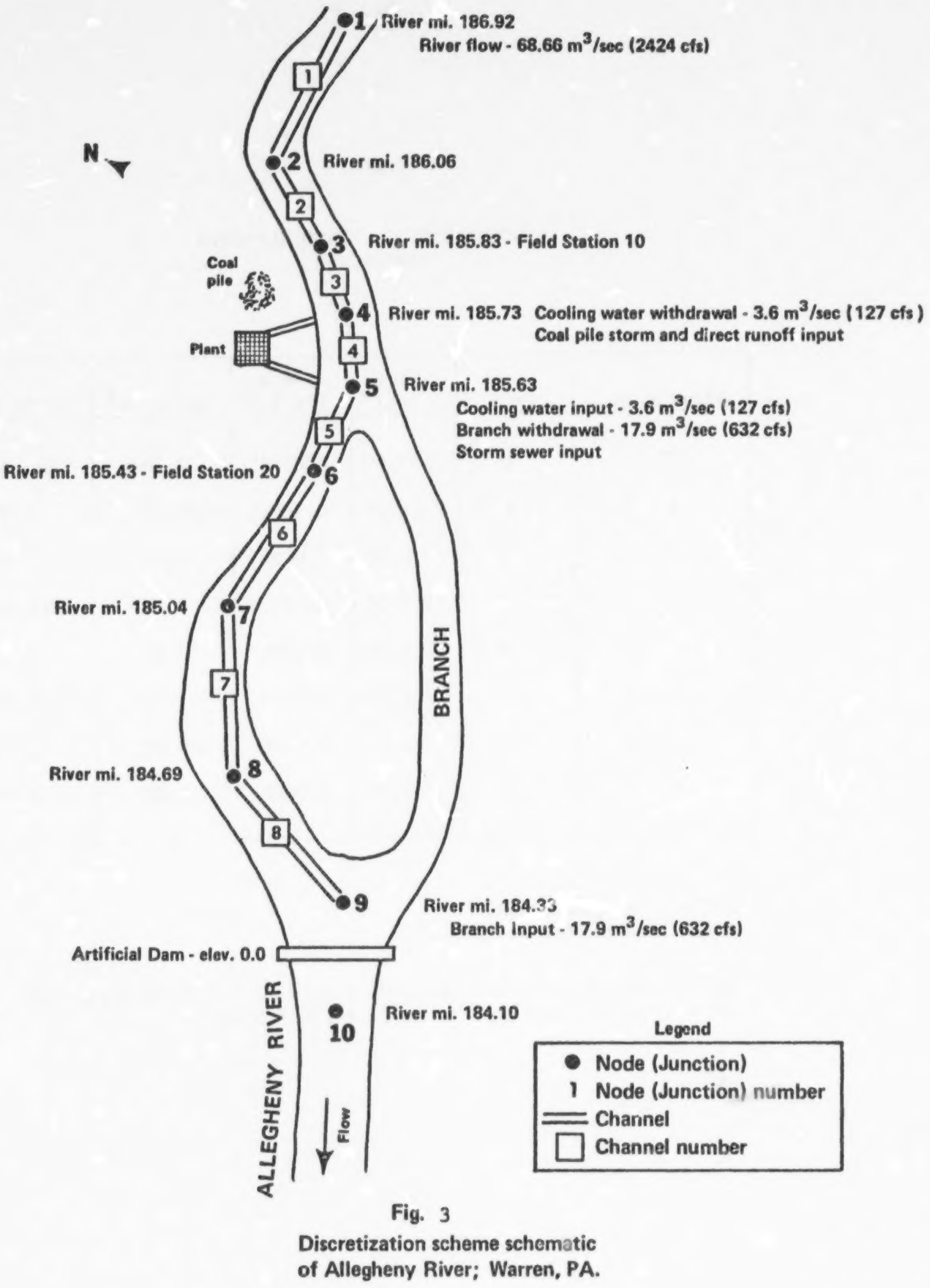
1 River mi. 186.92
River flow - 68.66 m³/sec (2424 cfs)
2 River mi. 186.06
3 River mi. 185.83 - Field Station 10
4 River mi. 185.73 Cooling water withdrawal - 3.6 m³/sec (127 cfs)
Coal pile storm and direct runoff input
5 River mi. 185.63
Cooling water input - 3.6 m³/sec (127 cfs)
Branch withdrawal - 17.9 m³/sec (632 cfs)
Storm sewer input
River mi. 185.43 - Field Station 20 6
River mi. 185.04 7
River mi. 184.69 8
9 River mi. 184.33
Branch input - 17.9 m³/sec (632 cfs)
Artificial Dam - elev. 0.0
10 River mi. 184.10
N
Coal pile
Plant
BRANCH
ALLEGHENY RIVER
Flow
1
2
3
4
5
6
7
8
Legend
● Node (Junction)
1 Node (Junction) number
Channel
Channel number

Fig. 3
Discretization scheme schematic
of Allegheny River; Warren, PA.

TABLE 4

DISCRETIZATION: RIVER ELEMENTS
WARREN, PA

Nodes (Junctions)

Junction Number	Surface Area (Sq M)	Channels Entering Junction							
1	184072.00	1	0	0	0	0	0	0	0
2	111646.00	2	1	0	0	0	0	0	0
3	29350.00	3	2	0	0	0	0	0	0
4	23184.00	4	3	0	0	0	0	0	0
5	39078.00	5	4	0	0	0	0	0	0
6	68644.00	6	5	0	0	0	0	0	0
7	75948.00	7	6	0	0	0	0	0	0
8	80203.00	8	7	0	0	0	0	0	0
9	47265.00	8	0	0	0	0	0	0	0
10	47265.00	0	0	0	0	0	0	0	0

Channels

Channel Number	Length (M)	Width (M)	Manning Coefficient	Bottom Elev*	Junctions at Ends	
1	1384.	133.	0.033	-1.7	1	2
2	370.	106.	0.033	-1.6	2	3
3	161.	121.	0.033	-1.4	3	4
4	161.	167.	0.033	-1.2	4	5
5	307.	167.	0.033	-1.2	5	6
6	460.	187.	0.033	-1.2	6	7
7	383.	172.	0.033	-1.0	7	8
8	690.	137.	0.033	-0.4	8	9

* Measured positive downward from data plane.

Figure 4. The four watersheds discharge to the Delaware River at two inlet points represented as Elements 2 and 11. The first watershed (Element 1) represents the ash handling and ash pile drainage area. The runoff from this area enters the Delaware River at Element 2. The second watershed (Element 3) is the drainage area for the plant substation, the third watershed (Element 5) is the drainage area for the coal pile, and the fourth watershed (Element 8) is the drainage area adjacent to the plant. Stormwater runoff from these three watersheds enters a storm sewer system (described by Elements 4, 6, 7, 9, and 10) which in turn discharges to the Delaware River through Element 11. The physical dimensions for each of these elements are listed in Table 5.

Based on the physical characteristics of the Delaware River and the location of the stormwater discharges to the river, the Delaware River was divided into seven nodes and five channels, as illustrated in Figure 5. Background river flow and pollutant concentrations enter node 1. Stormwater runoff discharges from the ash handling and ash pile area enter the river at node 3, and the stormwater runoff discharge from the substation, coal pile, and the plant area enter the river at node 4. Cooling water for the power plant is withdrawn at node 3 and is discharged at node 4. As with the Warren discretization scheme, an artificial dam, i.e., a dam with no elevation above the river bottom, was placed between nodes 6 and 7. Channels connect each of the nodes except where the nodes are interrupted by the dam. The physical characteristics for the node and channel discretization scheme are listed in Table 6.

As described previously in this paper, the amount of pollutant washed

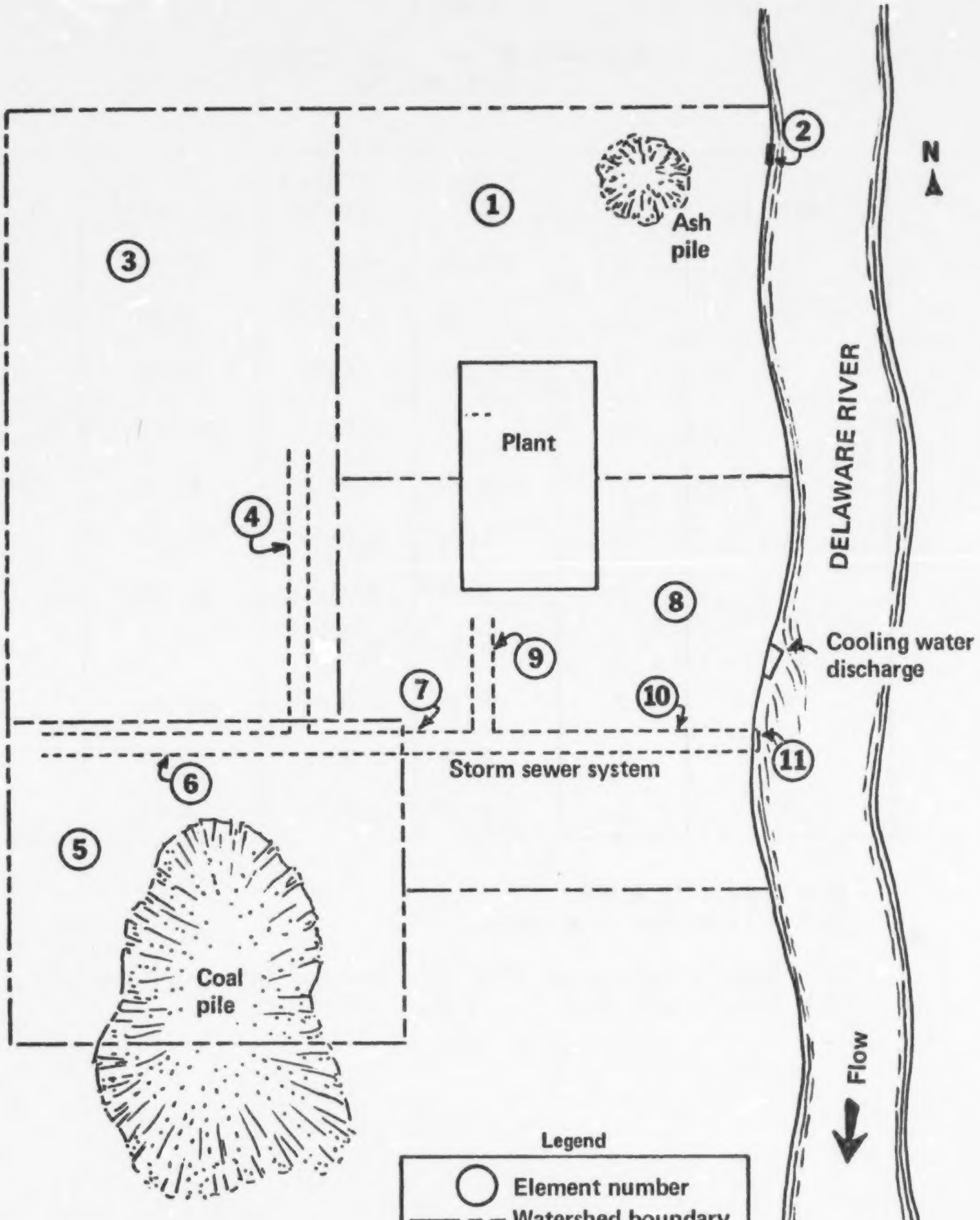
①
Ash pile
②
N
③
Plant
DELAWARE RIVER
④
⑧
Cooling water discharge
⑨
⑦
⑩
⑪
⑥
Storm sewer system
⑤
Coal pile
Flow
Legend
Element number
Watershed boundary

Fig. 4
Discretization scheme schematic of land area; Portland, PA.

TABLE 5

DISCRETIZATION: LAND ELEMENTS
PORTLAND, PA

Element No.	Type[1]	Width (Ft)	Slope (Ft/Ft)	AR OR GL[2]	PI OR DF[2]
1	1	808.00	0.0500	13.36	50.00
2	2	0.00	0.0000	0.00	0.00
3	1	1220.00	0.0080	17.48	33.33
4	2	1.75	0.0100	817.00	1.66
5	1	698.00	0.0020	11.90	100.00
6	2	1.75	0.0169	462.00	1.66
7	2	3.00	0.0096	223.00	2.85
8	1	1320.00	0.0500	10.23	100.00
9	2	1.75	0.0100	442.00	1.66
10	2	3.00	0.0096	452.00	2.85
11	2	0.00	0.0000	0.00	0.00

[1] Type 1 is a watershed
Type 2 is a pipe or manhole

[2] AR = Area of watershed (AC); PI = Percent imperviousness (%)
GL = Pipe length (Ft) ; DF = .95 * width

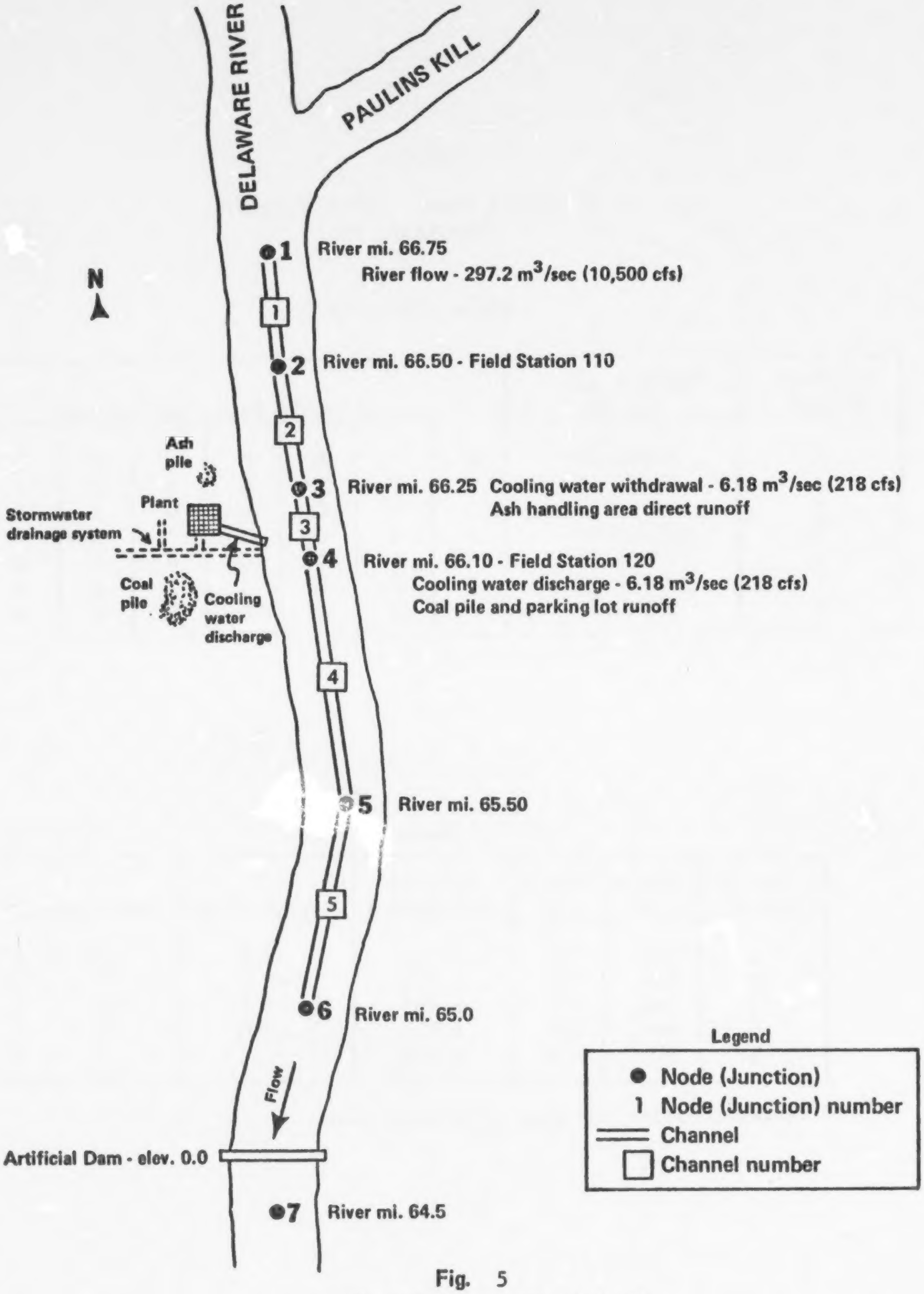
DELAWARE RIVER
PAULINS KILL
N
1 River mi. 66.75
River flow - 297.2 m³/sec (10,500 cfs)
1
2 River mi. 66.50 - Field Station 110
2
Ash pile
3 River mi. 66.25 Cooling water withdrawal - 6.18 m³/sec (218 cfs)
Ash handling area direct runoff
Plant
Stormwater drainage system
3
4 River mi. 66.10 - Field Station 120
Cooling water discharge - 6.18 m³/sec (218 cfs)
Coal pile and parking lot runoff
Coal pile
Cooling water discharge
4
5 River mi. 65.50
5
6 River mi. 65.0
Flow
Artificial Dam - elev. 0.0
7 River mi. 64.5
Legend
● Node (Junction)
1 Node (Junction) number
Channel
Channel number

Fig. 5
Discretization scheme schematic
of Delaware River; Portland, PA.

TABLE 6

DISCRETIZATION: RIVER ELEMENTS
PORTLAND, PA

Nodes (Junctions)

Junction Number	Surface Area (Sq M)	Channels Entering Junction							
1	93861.00	1	0	0	0	0	0	0	0
2	92022.00	2	1	0	0	0	0	0	0
3	74722.00	3	2	0	0	0	0	0	0
4	130490.00	4	3	0	0	0	0	0	0
5	172638.00	5	4	0	0	0	0	0	0
6	71779.00	5	0	0	0	0	0	0	0
7	71779.00	0	0	0	0	0	0	0	0

Channels

Channel Number	Length (M)	Width (M)	Manning Coefficient	Bottom Elev*	Junctions at Ends	
1	402.	233.	0.033	-2.8	1	2
2	402.	224.	0.033	-2.7	2	3
3	241.	245.	0.033	-3.4	3	4
4	966.	209.	0.033	-3.5	4	5
5	805.	178.	0.033	-1.6	5	6

*Measured positive downward from data plane.

from the land surface during a storm is, in part, related to the initial (pre-storm) mass of pollutant on the land surface. The initial pollutant mass load is equal to the dust and dirt accumulation rate multipled by the area of the watershed with that dust and dirt accumulation rate, the number of dry days between storms, and the amount of a particular pollutant in the dust and dirt. The dust and dirt accumulation rate and the amount of a particular pollutant in the dust and dirt used as inputs to the model run were determined from dust field sampling programs for both the Warren and Portland Generating Stations. The area of the watershed with that dust and dirt accumulation rate and the number of dry days between storms were determined from discretization schemes and meteorological records.

The results of the dust and dirt sampling and analyses programs are summarized in Table 7. At the Warren Generating Station, one dust and dirt accumulation rate (.003 lbs/dry day - ft^2) was representative of all the watersheds. At the Portland Station, two dust and dirt accumulation rates were developed -- one for the coal pile, plant, and substation watersheds (.003 lbs/dry day - ft^2) and one for the ash handling watershed (.00055 lbs/dry day - ft^2). The amount of pollutant in the dust and dirt also varied between the Warren and Portland Generating Stations. Total suspended solids and sulfate levels were slightly higher at Portland. while total iron, manganese, aluminum, and total dissolved solid levels were substantially lower.

Storm activity input data consisted of field measurements of rainfall intensity. These results are summarized in Table 8. The storm of

TABLE 7

SUMMARY RESULTS OF DUST AND DIRT SAMPLING PROGRAM AS INPUT TO MODEL

Location	Activity	Dust and Dirt Accumulating Rate (Lbs/Dry Day-Ft^2)	mg Pollutant Per Gram of Dust and Dirt					
			TSS	Sulfates	Total Fe	Manganese	Aluminum	TDS
Warren Generating Station	Entire Plant Area	.003[1]	993.5	1.0	18.7	.3	3.4	6.5
Portland	Coal Pile and Adjacent Area	.0003[2]	997.91	1.11	.016	.003	.015	2.09
	Ash Handling Area	.00055[2]	998.39	1.18	.004	.0013	.0066	1.61

[1] The dust and dirt load increased at this accumulation rate without reaching an ultimate level over a 15-day period.

[2] The dust and dirt load increased at this accumulation rate for approximately four days after which the total dust and dirt load remained at a constant level.

TABLE 8

SUMMARY OF STORM ACTIVITY

Location	Date	Storm Activity	Rainfall Intensity		Total Rainfall (in)	Comments
			(Time)	(in/hr)		
Warren Generating Station	8-26-76	Shower	1435-1455	0.33	0.11	Last Prior Storm Occurred on 8-15-76
Warren Generating Station	9-17-76	Steady Drizzle, Intermittent Showers-Heavy at Short Intervals	0800	0.00	0.33	
			0930	0.04		
			1050	0.05		
			1130	0.11		
			1230	0.07		
			1510	0.03		
Portland Generating Station	10-20-76	Steady Drizzle, Intermittent Showers-Heavy at Short Intervals	0800	0.00	1.55	Last Prior Storm Occurred on 10-13-76
			0810	0.06		
			0910	0.10		
			1010	0.05		
			1110	0.09		
			1140	0.16		
			1155	0.16		
			to 2130	0.12*		

*Average Intensity Based on Measured Value for Cumulative Rainfall in that Time Period.

September 17, 1976, at the Warren Generating Station, was used for model calibration. This storm lasted approximately seven hours and was a steady drizzle with intermittent, short but heavy, showers. The maximum rainfall intensity was 0.11 inches/hour, and the total rainfall was 0.33 inches. The storm of August 26, 1976, was used for model verification at Warren. This storm was a short (20-minute) shower with a maximum rainfall intensity of 0.33 inches/hour, and a total rainfall of 0.11 inches. The storm used for the model run at Portland occurred on October 20, 1976. The storm lasted approximately 14 hours and was a steady drizzle with intermittent, short but heavy, showers. The maximum rainfall intensity was 0.16 inches/hour, and the total rainfall was 1.55 inches.

Other input items of fundamental concern to SSWMM-RECEIV II are background flow and pollutant loadings in the receiving waters. Background conditions are those flow and pollutant loadings which are not influenced by the stormwater runoff of the particular site being studied.

In the case of the Warren and Portland Generating Stations, background conditions were measured in the river upstream of the plant stormwater discharges. Background flows and pollutant loadings were computed as a three-day average of the river field measurements at the upstream station for one day prior to the storm, the day of the storm, and one day after the storm. The background conditions were computed in this manner since a model restriction requires that the background inputs to the model remain unchanged for the model simulation period. A three-day simulation was desired to allow computational stability and to monitor the storm-induced flows and pollutant concentrations for up to one day after the storm.

4.2 Model Test Results

The model results were compared to field measurements to test the validity of the model where comparable information was available and at time intervals where maximum runoff flows and pollutant loadings occurred in the model. A comparative factor of 4 was considered to be adequate for model development purposes.

For the storm of September 17, the initial model run at the Warren Generating Station, the modeled stormwater runoff flow was 0.4 of the measured flow, and the modeled stormwater runoff pollutant concentrations were within a factor of 4; (i.e., the model concentration divided by the measured concentration varied between .25 and 4.0) for total suspended solids, total iron, manganese, and aluminum, but were greater than a factor of 4 for sulfates and total dissolved solids. Modeled and measured pollutant concentrations in the Allegheny River compared within a factor of 3. The results are shown in Table 9.

In the calibration model run at the Warren Generating Station for the storm of September 17, the impervious area water retention storage depth was reduced from .062 inches to .001 inches to increase the modeled percentage of the total rainfall that was runoff. This change was made since the area was almost completely impervious. The percentage of runoff, therefore, should be approximately equal to 100%. In the initial model run, it was only 86%. In the calibration model run, the percentage runoff was 99%. The impervious area water retention storage was maintained at .001 inches for the remaining model runs.

In the calibrated model run at Warren for the storm of September 17,

TABLE 9.

COMPARISON OF MODEL RESULTS TO FIELD DATA
STORM OF SEPTEMBER 17 (INITIAL RUN)
WARREN GENERATING STATION

SSWMM

	Model[1] Inlet 3		Meas[1] Sta. 34	Factor Model/ Meas	Model[2] Inlet 5		Meas[2] Sta. 31 32,33	Factor Model/ Meas	Model[3] Inlet 8		Meas[3] Sta. 42	Factor Model/ Meas
Flow (CFS)	.26		.68	.4	.15		No Data	-	.12		No Data	-
Pollutant	#/min	mg/l	mg/l		#/min	mg/l	mg/l		#/min	mg/l	mg/l	
TSS	6.635	6819	4028.	1.7	3.078	3163	2058 - 5410	1.5-.6	2.434	5420	2695.	2.0
SO_4	.0325	33.4	2100.	.02	.0174	31.0	225-475.	.1-.06	.0213	5.7	3000.	.002
Tot.Fe	.607	623.8	700.	.9	.325	579	153-300	3.8-1.9	.398	886.	1025.	.9
Mn	.010	10.3	10.4	1.0	.005	8.9	3.5-6.0	2.5-1.5	.006	13.4	16.0	.8
Al	.110	113.	79.0	1.4	.059	105.1	23.5-71.	4.5-1.5	.072	160.3	111.0	1.4
TDS	.211	216.8	3135.	.07	.113	5.3	357-618	.01-.008	.138	307.3	5456.	.06

[1] Time = Model = 1130; Meas = 1110 - 1120
[2] Time = Model = 1115; Meas = 1100 - 1115
[3] Time = Model = 1030; Meas = 1020

RECEIV[4]

Quality

Pollutant	Model Conc.[5] (mg/l)	Junction	Background (mg/l)	Measurement[6] Sta. 20 (mg/l)	Factor Model/Meas
TSS	13.536	6	11.610	4.5	3.0
SO_4	16.174	6	16.170	16.0	1.0
Tot.Fe	.355	6	.190	.74	.5
Mn	.033	6	.030	.06	.6
Al	1.030	6	1.000[7]	1.000[7]	1.0
TDS	105.228	6	105.198	99.00	1.1

[4] Quantity - Storm has no effect on flow characteristics
[5] Time = 1200
[6] Time = 1150 - 1210
[7] 1.00 = Non-Detectable Limit

the modeled stormwater runoff flow and pollutant concentrations and the modeled river pollutant concentrations compared to the field measurements with approximately the same degree of accuracy as did the initial model run for the storm of September 17. The results are shown in Table 10.

For the storm of August 26, the verification model run at the Warren Generating Station, the modeled stormwater pollutant concentrations also compared to the field measurements with approximately the same degree of accuracy as did the calibration model run for the storm of September 17. Modeled and measured pollutant concentrations in the Allegheny River compared within a factor of 4. The results are shown in Table 11.

For the storm of October 20, the model run at the Portland Generating Station, modeled stormwater pollutant concentrations were different from field measurements by greater than a factor of 4. Modeled and measured pollutant concentrations in the Delaware River compared within a factor of 5. Results are shown in Table 12.

The model was not calibrated at Portland because stormwater flow field measurements were not available due to measurement difficulties, and it is first necessary to calibrate flow in the model before any other model adjustments are warranted.

TABLE 10

COMPARISON OF MODEL RESULTS TO FIELD DATA
STORM SEPTEMBER 17 (CALIBRATION RUN)
WARREN GENERATING STATION

SSWMM

	Model[1] Inlet 3		Meas[1] Sta. 34	Factor Model/ Meas	Model[2] Inlet 5		Meas[2] Sta. 31, 32,33	Factor Model/ Meas	Model[3] Inlet 8		Meas[3] Sta. 42	Factor Model/ Meas
Flow (CFS)	.26		.68	.4	.15		No Data	-	.13		No Data	-
Pollutant	#/min	mg/l	mg/l		#/min	mg/l	mg/l		#/min	mg/l	mg/l	
TSS	6.501	6681	4028.	1.6	3.01	5362.	2058 - 5410	2.6-1.0	2.754	5660	2695.	2.1
SO_4	.0263	27.0	2100	.01	.0141	25.1	225-475.	.1-.05	.0191	39.2	3000.	.01
Tot.Fe	.493	506.6	700	.7	.263	468.5	153-300	3.1-1.6	.358	736.	1025.	.7
Mn	.008	8.2	10.4	.8	.004	7.1	3.5-6.0	2.0-1.2	.006	12.3	16.0	.8
Al	.090	92.5	79.0	1.2	.048	85.5	23.5-71.	3.6-1.2	.065	133.6	111.0	.8
TDS	.171	175.7	3135	.06	.091	162.1	357-618	.4-.3	.124	255.	5456.	.05

[1] Time = Model = 1130; Meas = 1110 - 1120
[2] Time = Model = 1115; Meas = 1100 - 1115
[3] Time = Model = 1030; Meas = 1020

RECEIV[4]

Quality

Pollutant	Model Conc.[5] (mg/l)	Junction	Background (mg/l)	Measurement[6] Sta. 20 (mg/l)	Factor Model/Meas
TSS	13.496	6	11.610	4.5	3.0
SO_4	16.173	6	16.170	16.0	1.0
Tot.Fe	.324	6	.190	.74	.4
Mn	.032	6	.030	.06	.5
Al	1.024	6	1.000[7]	1.000[7]	1.0
TDS	105.217	6	105.198	99.00	1.1

[4] Quantity - Storm has no effect on flow characteristics
[5] Time = 1200
[6] Time = 1150 - 1210
[7] 1.00 = Non-Detectable Limit

TABLE 11

COMPARISON OF MODEL RESULTS TO FIELD DATA
STORM AUGUST 26 (VERIFICATION)
WARREN GENERATING STATION

SSWMM

	Model[1] Inlet 3		Meas[1] Sta. 34	Factor Model/ Meas	Model[2] Inlet 5		Meas[2] Sta. 31 32 33	Factor Model/ Meas	Model[3] Inlet 8		Meas[3] Sta. 42	Factor Model/ Meas
Flow (CFS)			No Data		.21		No Data	-			No Data	
Pollutant	#/min	mg/l	mg/l		#/min	mg/l	mg/l		#/min	mg/l	mg/l	
TSS					1.939	2467.	1027 - 2965.	2.4-.83				
SO_4			No Data		.0143	18.2	1750 - 10510.	.01-.002				
Tot.Fe					.267	340.	108-700	3.1-.48			No Data	
Mn					.004	5.1	9.6-45.	.53-.1				
Al					.049	62.3	42.5-334	1.5-.2				
TDS					.093	118.	2405 - 8107.	.05-.01				

[1] Time = No Data During Storm
[2] Time = 1445
[3] Time = No Data During Storm.

RECEIV[4]

	Quality				
Pollutant	Model Conc.[5] (mg/l)	Junction	Background (mg/l)	Measurement[6] Sta. 20 (mg/l)	Factor Model/Meas
TSS	7.839	6	7.73	No Data	-
SO_4	12.481	6	12.48	No Data	-
Tot.Fe	.249	6	.23	.06	4.2
Mn	.030	6	.030	.013	2.3
Al	1.003	6	1.000[7]	1.000[7]	1.0
TDS	114.502	6	114.5	No Data	-

[4] Quantity - Storm has no effect on flow characteristics
[5] Time = 1600
[6] Time = 1550 - 1650
[7] 1.00 = Non-Detectable Limit

TABLE 12

COMPARISON OF MODEL RESULTS TO FIELD DATA
STORM OCTOBER 20 (INITIAL RUN)
PORTLAND GENERATING STATION

SWMM

	Model[1] Inlet 2		Measure[1] Station 131, 132	Factor Model/Measure	Model[2] Inlet 11		Meas[2] Sta. 134B	Factor Model/Meas
Flow (CFS)	.83		No Data	-	2.34		No Data	-
Pollutant	#/min	mg/l	mg/l		#/min	mg/l	mg/l	
TSS	.543	175.	2344-10932	.07-.02	1.015	116.	280.	.4
SO_4	.0037	1.2	1200-1600	.001-.0008	.0058	.7	400.	.002
Tot.Fe	<.001	<.32	73-245	.004-.001	<.001	<.1	385.	.0002
Mn	<.001	<.32	.03-2.5	10.-.13	<.001	<.1	1.75	.06
Al	<.001	<.32	125-138	.002-.002	<.001	<.1	50.	.002
TDS	.005	1.6	1843-2504	.0008-.0006	.011	1.2	698.	.002

[1] Time = 1115
[2] Time = 1045

RECEIV[3]

Quality

Pollutant	Model Conc.[4] (mg/l)	Junction	Background (mg/l)	Measurement[5] Sta. 120 (mg/l)	Factor Model/Meas
TSS	16.070	4	15.999	7.1	2.3
SO_4	14.611	4	14.618	9.0	1.6
Tot.Fe	.570	4	.570	.45	1.3
Mn	.050	4	.050	.01	5.0
Al	1.000	4	1.000[6]	1.000[6]	1.0
TDS	67.455	4	67.486	45.7	1.5

[3] Quantity - Storm has little effect on flow characteristics in river (Less than .05% increase in river flow at max. storm discharge).

[4] Time = 1200
[5] Time = 1130 - 1200 and 1230 - 1300
[6] 1.000 = Non-Detectable Limit.

5.0 EVALUATION OF MODEL DEVELOPMENT PROGRAM

The work completed in this study indicates that SSWMM-RECEIV II is capable of predicting the quantity and quality of stormwater runoff and its impact on receiving waters for specific industries, but model limitations do exist.

SSWMM-RECEIV II is a versatile stormwater and receiving water model suited for industrial application. It is inherently flexible so that it is appoicable to many industries with only minor data input modifications.

The specific utility industry application described in this study has demonstrated that, where adequate field data were available, SSWMM-RECEIV II results compared favorably to field measurements. At the Warren Generating Station, calibrated model results for stormwater runoff flow and pollutant concentrations compared within a factor of 4 and river pollutant concentrations compared within a factor of 3 to field measurements. The model-field measurement comparative factor of 4 was maintained for a second storm at Warren, indicating that the calibrated model could predict the effects of different storm conditions with the same degree of accuracy established in model calibration. In essence, the model was verified, increasing model credibility.

Some difficulties were encountered in this model study. Modeled stormwater runoff concentrations of total dissolved solids and sulfates at the Warren Generating Station were different from the field-measured values by greater than a factor of 4. In addition, due to measurement difficulties, adequate field data were not available to ascertain the comparative validity of the model at the Portland Generating Station for either stormwater runoff or the receiving water.

Inherent model limitations include the lack of capability to simulate storm erosion of infinite sources; i.e., material storage piles, and to simulate stormwater percolation through material storage piles.

Although difficulties were encountered, and additional work is needed to increase model credibility and usefulness, SSWMM-RECEIV II has been demonstrated to be a valid stormwater runoff and receiving water model suited to industrial application.

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CURRENT STATUS OF PROCESS FUGITIVE PARTICULATE EMISSION ESTIMATING TECHNIQUES

By

John M. Zoller, Thomas A. Janszen
PEDCo Environmental, Inc.

and

Gilbert H. Wood
U.S. Environmental Protection Agency

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CURRENT STATUS OF PROCESS FUGITIVE PARTICULATE EMISSION ESTIMATING TECHNIQUES

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ABSTRACT

This presentation synopsizes the availability and status of information useful for estimating the sources and quantities of particulate matter classified as fugitive process particulate emissions. As part of an EPA-sponsored technical information effort, 24 major industrial classifications were investigated. Fugitive emissions data acquired through literature search, evaluation of pertinent on-going EPA studies, interview of trade associations, and on-site plant visitations has been tabularized. They have been ranked according to a set of subjective criteria in an effort to assign reliability indices. These indices are presented by the authors in order to qualify both the current status and possible utilization of these data for "emission factor" purposes.

INTRODUCTION

PEDCo Environmental, Inc. has recently completed a project report for the U.S. Environmental Protecton Agency* entitled "Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions." The document was prepared as guidance for air pollution control agencies in developing revisions, where necessary, to particulate matter control strategies. A data base was assembled from literature sources, on-going U.S. Environmental Protection Agency in-house or contractor project activities, air pollution control agency records and files, interview of trade associations, and visits to industrial facilities emitting and/or controlling fugitive particulate emissions.

"Industrial Process Fugitive Particulate Emissions," often referred to hereafter as "IPFPE," result from either one or both of the following categorical groupings of particulate emission sources - "fugitive emissions" and "fugitive dust" originating within industrial facilities. Fugitive dust emissions are generally related to natural or man-associated dusts (particulate only) that become airborne due to the forces of wind, man's activity, or both. Fugitive emissions, on the other hand, include those particulates that are emitted from industry-related operations and which escape to the atmosphere through windows, doors, vents, etc.; not through a primary exhaust system, such as a stack, flue or control system. Therefore, for the purpose of this investigation, Industrial Process Fugitive Particulate Emissions (IPFPE) were defined as ... "Particulate matter which escapes from a defined process flow stream due to leakage, materials charging/handling, inadequate operational control, lack of reasonably available control technology, transfer, or storage.

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* Prepared under Contract No. 68-02-1375, Task Order No. 33. Publication No. EPA-450/3-77-010. Gilbert H. Wood, EPA Project Officer.

The document "Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions" contained information on control technology for sources of IPFPE, estimating the air quality impact of IPFPE, and integration of IPFPE impacts into the State Implementation Planning process. Another part of that document discussed sources of industrial process fugitive particulate emissions, and the topic of this paper is the development of that information.

SOURCES OF INDUSTRIAL PROCESS FUGITIVE PARTICULATE EMISSIONS

For each of 24 major industrial categories with potential IPFPE sources, the following information was given in the guidance document:

- Process description
- Identification of IPFPE sources
- Emission estimates and an example plant inventory of IPFPE sources

- IPFPE emission characteristics
- Control technology options for IPFPE sources

A difficult part of this task was to develop for all 24 selected industrial categories, a range of emission estimates for each potential IPFPE source. This is a job that would require years of testing and the expenditure of large sums of money for definitive estimates. Since the determination of emission rates was but one part of the guidance document, testing was not in the scope of work. Therefore an extensive literature search was made to obtain available fugitive emission estimates. Obviously, estimates could not be found for all fugitive sources. For the sources where an emission rate could not be found in the literature, best engineering judgement was used to estimate the emissions. This paper discusses development of the emission estimates and an example plant inventory.

A range of emission estimates was presented where adequate information was available. It was not the intent of the study to determine a single factor (average or typical) for each IPFPE source, but rather to present a range of values. However, when only one estimate was found in the literature, that number was shown. For sources where emission factors were not available in the literature, estimates were based on engineering judgment using emission factors for similar sources, observations during plant visits, calculations from source reported or test data, or a percent of the stack emissions.

A reliability rating was indicated for each fugitive emission estimate. This was an indicator of the supportive data used to develop the factor. The reliability ratings used correspond to the rating system used in "Compilation of Air Pollutant Emission Factors," EPA Publication Number AP-42. The ratings in AP-42 are predominately applied to stack (nonfugitive) emissions, and are defined as follows:

A - Excellent

B - Above average

C - Average

D - Below average

E - Poor

All fugitive emission rates in the guidance document were determined to have ratings of C, D, or E. The criteria used to determine these ratings were:

C - Supportable by multiple test data.

D - Supportable by limited test data and engineering judgment.

E - Supportable by best engineering judgment (visual observation, emission tests for similar sources, etc.).

Fugitive emission factors supportable by multiple test data were given only a "C" (average) rating because of the difficulty in accurately measuring fugitive emissions as compared to measuring stack emissions. Also the plant to plant variations in emission rates were expected to be greater for fugitive sources than for nonfugitive sources. Factors based on engineering judgment (e.g., visual observation or emission tests for similar sources) were given an "E" (poor) rating. Factors with an "E" rating were at best order of magnitude estimates; therefore, actual emission rates at a given facility could differ significantly. Fugitive emission factors based on limited test data and engineering judgment were given a "D" (below average) rating.

A model plant IPFPE inventory was presented for each industry, but was not intended to represent a "typical" plant, only an example application of the uncontrolled fugitive emission estimates. An average for any range of factors presented was used in developing the inventory. For a specific plant, consideration of operating conditions must be made when selecting the emission rate. Credit must be given for controls or good operating practices that reduce emissions. Also, poor maintenance or operating procedures would likely result in an emission rate that is greater than average.

The Portland cement industry was selected to illustrate the development of the fugitive emission factors and their reliability ratings. Through this example, development of the fugitive emission factors and reliability ratings for the other industries (as shown in Appendix A) will be better understood.

DEVELOPMENT OF FUGITIVE PARTICULATE EMISSION FACTORS FOR THE PORTLAND CEMENT INDUSTRY

Figure 1 presents a process flow diagram for the Portland cement industry showing 22 potential fugitive particulate emission points. These emission points were identified as potential fugitive sources as a result of an extensive literature search and visits to several Portland cement plants. Each source is identified and explained in Table 1. Note that this table is reproduced as presented in the guidance document. In footnotes to the table, section numbers refer to sections in the guidance document and references cited are listed at the end of this paper.

Emissions Calculated from Literature Sources

Some factors were based on data presented in the literature. For Source 1, raw material unloading, the factor for coal was obtained from Reference 5. Since emission testing was not done to develop this factor, it was assigned a reliability rating of "E." The fugitive emission factor range for unloading other raw materials (clay, sand, and

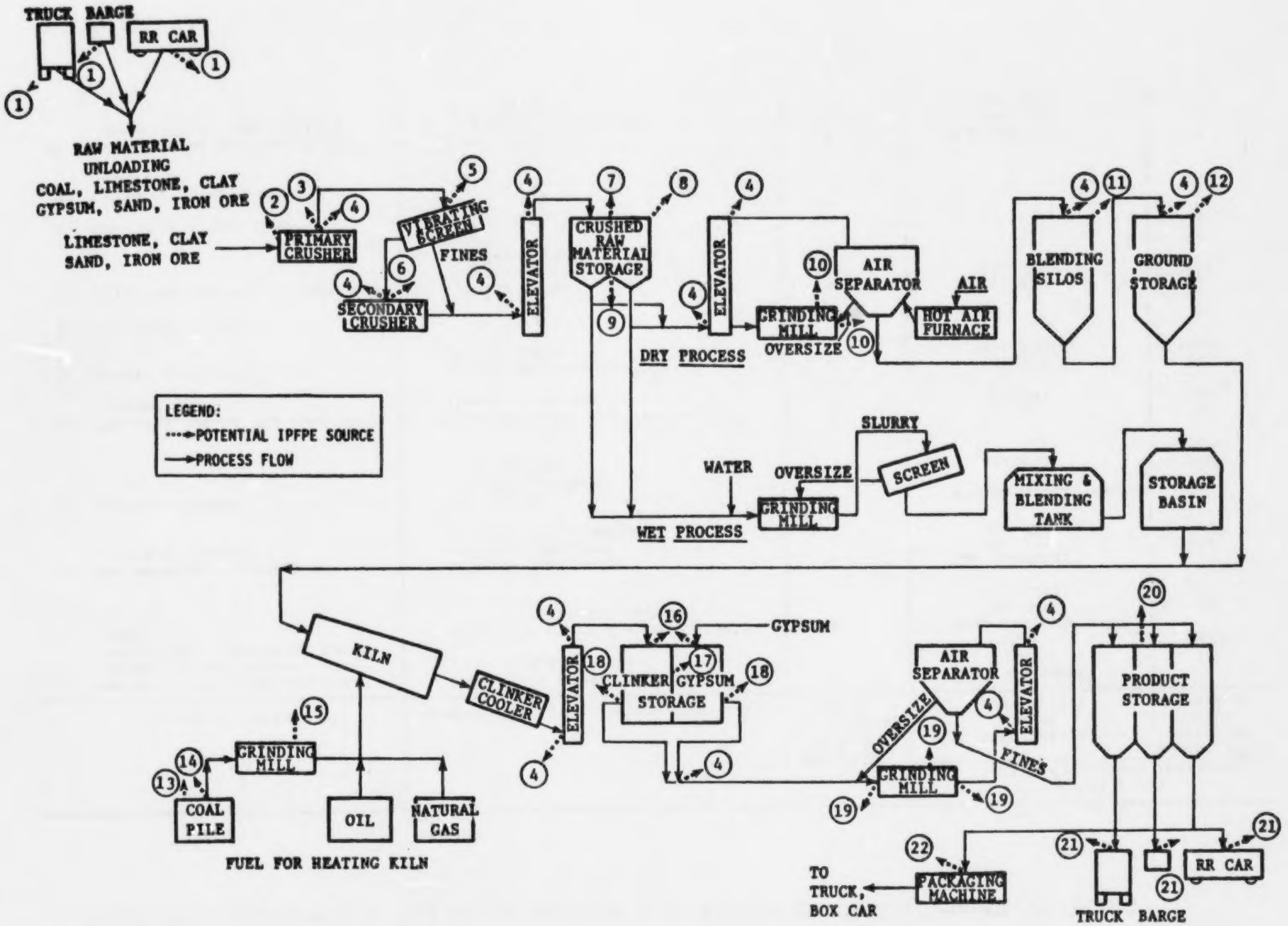
TRUCK
BARGE
RR CAR
RAW MATERIAL UNLOADING
COAL, LIMESTONE, CLAY GYPSUM, SAND, IRON ORE
LIMESTONE, CLAY SAND, IRON ORE
PRIMARY CRUSHER
VIBRATING SCREEN
FINES
SECONDARY CRUSHER
ELEVATOR
CRUSHED RAW MATERIAL STORAGE
DRY PROCESS
ELEVATOR
GRINDING MILL
OVERSIZE
AIR SEPARATOR
AIR
HOT AIR FURNACE
BLENDING SILOS
GROUND STORAGE
LEGEND:
POTENTIAL IPFPE SOURCE
PROCESS FLOW
WATER
OVERSIZE
SLURRY
SCREEN
GRINDING MILL
WET PROCESS
MIXING & BLENDING TANK
STORAGE BASIN
KILN
CLINKER COOLER
ELEVATOR
CLINKER
GYPSUM
STORAGE
GYPSUM
GRINDING MILL
COAL PILE
OIL
NATURAL GAS
FUEL FOR HEATING KILN
AIR SEPARATOR
ELEVATOR
OVERSIZE
FINES
GRINDING MILL
PRODUCT STORAGE
PACKAGING MACHINE
TO TRUCK, BOX CAR
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Figure 1. Process flow diagram for portland cement manufacturing showing potential industrial process fugitive particulate emission points.

Table 1. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PORTLAND CEMENT MANUFACTURING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
1. Raw material unloading (rail, barge, truck) gypsum, iron ore, clay, limestone, sand, coal	Coal: 0.2 kg/Mg material^{a} (0.4 lb/ton)	E	Coal unloaded^{n} 79,175 (87,197)	16 (17)
	Other: 0.015-0.2 kg/Mg material^{a} (0.03-0.4 lb/ton)	E	Materials unloaded^{n} 161,240 (177,576)	17 (19)
2. Raw material charging to primary crusher	0.00015-0.02 kg/Mg of rock charged^{b} (0.0003-0.04 lbs/ton)	D	Raw material^{o} 591,421 (651,345)	6 (7)
3. Primary crusher	0.25 kg/Mg of rock crushed^{c} (0.5 lbs/ton)	C	Raw material crushed 591,415 (651,338)	148 (163)
4. Transfer points and associated conveying	0.1-0.2 kg/Mq material handled^{d} (0.2-0.4 lb/ton)	E	591,415 (651,338)	89 (98)
5. Vibrating screen	0.74 kg/Mg screened^{e,f} (1.5 lbs/ton)	C	591,267 (651,175)	443 (488)
6. Secondary crusher	f	-	-	f
7. Unloading outfall to storage	1.5-2.5 kg/Mg raw material unloaded^{g,h} (3.0-5.0 lb/ton)	E	590,824 (650,687)	1,182 (1,300)
8. Raw material storage	h	-	-	h
9. Transfer to conveyor via clamshell	h	-	-	h
10. Raw grinding mill and feed/ discharge exhaust systems	0.05 kg/Mg raw material milled^{g} (0.1 lbs/ton)	E	Raw material 589,642 (649,387)	29 (32)

Table 1 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PORTLAND CEMENT MANUFACTURING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
11. Raw blending	0.02 kg/Mg raw material blended[g,j] (0.05 lbs/ton)	E	Raw material 589,613 (649,355)	12 (13)
12. Blended material storage	j	-	-	j
13. Coal storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[i] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Coal loaded 79,175 (87,197)	3 (3)
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[i] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Coal stored 79,175 (87,197)	7 (8)
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[i] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Coal loaded out 79,175 (87,197)	4 (4)
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[i] $\left(\frac{(0.11)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}\ \text{lb/ton}\right)$	D	Coal stored 79,175 (87,197)	12 (13)

Table 1 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PORTLAND CEMENT MANUFACTURING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/year (tons/year)	Uncontrolled emissions (tons/yr)
14. Transfer of coal to grinding mill	Neg-0.1 kg/Mg transferred^{g} (0.2 lbs/ton)	D	coal transferred 79,173 (87,195)	8 (9)
15. Leakage from coal grinding mills	Negligible^{g}	E	-	-
16. Unloading-clinker/gypsum outfall to storage	2.5-5.0 kg/Mg of clinker and gypsum^{g,k,l} (5.0-10.0 lbs/ton)	E	clinker/gypsum 405,022 (446,059)	1,519 (1,671)
17. Clinker/gypsum storage	l	-	-	l
18. Clinker/gypsum load-out	l	-	-	l
19. Finish grinding with leaks from mill and from feed/discharge exhaust systems	0.05 kg/Mg of cement^{g} (0.1 lbs/ton)	E	grinding feed^{p} 403,627 (444,525)	20 (22)
20. Cement silo vents	Negligible^{g}	E	-	-
21. Cement loading	0.118 kg/Mg of cement loaded^{m} (0.236 lbs/ton)	E	cement loaded 375,443 (413,485)	44 (49)
22. Cement packaging	Neg-0.005 kg/Mg packed^{g} (0.01 lbs/ton)	E	cement packaged 28,164 (30,980)	negligible

Table 1 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PORTLAND CEMENT MANUFACTURING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)

[a] Estimate based on data presented in Section 2.1.2. Range shown is for taconite and coal railcar unloading.

[b] Reference 1.

[c] Estimated based on crushed stone emission factors (Reference 2). Note that approximately 80 percent of these emissions will fall out on plant property.

[d] Estimate based on data presented in Section 2.1.1.

[e] Estimated based on crushed stone emission factors (Reference 2). Note that approximately 60 percent of these emissions will fall out on plant property.

[f] Emissions for point 6 are included in emissions from point 5.

[g] Engineering judgement based on visual observations during plant visits.

[h] Emissions from point 9 are included in emissions from point 7.

[i] For complete development of this emission factor, refer to Section 2.1.4. For source 13 it was assumed that S = 4.0, D = 90, PE = 100, and $K_1 = 0.75$, $K_2 = 0.5$, and $K_3 = 0.75$. Reference 3.

[j] Emissions from points 12 are included in emissions from point 11.

[k] Based on partially enclosed structure: open on both ends with roof.

[l] Emissions from points 17 and 18 are included in emissions from point 16.

[m] Reference 4. Based on tests of mechanical unloading of cement to hopper and subsequent transport of cement by enclosed bucket elevator to elevated bins with a fabric sock over the bin vent.

[n] 88,930 Mg (97,940 tons) - clay
57,879 Mg (63,743 tons) - sand
14,431 Mg (15,893 tons) - iron ore
79,175 Mg (87,197 tons) - coal

[o] Raw material charged, crushed, screened, and crushed (2nd)
- 88,930 Mg (96,751 tons) - clay
- 57,879 Mg (62,965 tons) - sand
- 14,431 Mg (15,698 tons) - iron ore
- 490,105 Mg (539,763 tons) - limestone

[p] Includes 124 Mg (137 tons) of hydrophobe and grinding aid.

iron ore) was assumed equal to the range of emissions for taconite railcar unloading. The taconite factors were derived from data presented in Reference 6. Since the source of data in this reference was unknown an "E" rating was assigned.

The factors for Source 2, raw material charging (truck dump) to primary crusher, were obtained from Reference 1 and were based on limited test data and engineering judgment. As reported in that reference:

> "Midwest Research Institute, in a sampling study of aggregate handling operations, estimated that dumping of crushed rock or gravel onto storage piles accounted for about 12 percent of the total emissions of 0.33 lb/ton from handling, or 0.04 lb/ton. The truck dumping operation was not sampled in isolation from the other handling operations and the estimate of 12 percent was partially subjective. This emission factor for dumping of aggregate onto storage piles was recently published in Supplement 5 of EPA's Compilation of Air Pollutant Emission Factors.[7]
>
> Monsanto Research determined an emission rate of 0.00034 lb/ton for truck unloading at the hopper of a primary crusher.[8] The material being handled was quarried granite with very little fine material present."

Since both engineering judgment and test data were used, this range was assigned a "D" rating.

The factors for Source 4, transfer points and associated conveying, were also obtained from Reference 1. These factors represent total transfer and conveying operations at coal mines. Because the transfer and conveying emissions for the Portland cement plant were assumed the same as the coal plant factors, an "E" rating was assigned.

Emission factors for the primary crusher, Source 3; the vibrating screen, Source 5; and the secondary crusher; Source 6, were taken from the EPA publication "Compilation of Air Pollutant Emission Factors," AP-42.[2] These factors represent uncontrolled fugitive emissions for stone crushing facilities and received a rating of "C" in AP-42. When using these factors to estimate impact on air quality, note that approximately 80 percent of the primary crushing emissions and 60 percent of the screening and secondary crushing emissions will settle out on plant property.

The coal storage pile factors, Source 13, were obtained from Reference 3. These factors were a refinement of the aggregate storage pile factor presented in AP-42.[2] Note that these formulas were preliminary and therefore subject to further refinement and change when test results become available. The storage pile emission factors were presented for the unit operations of loading onto the pile, vehicular traffic around the pile, loading out, and wind erosion. Correction parameters were also incorporated into these equations. Activity factors ($K_{1,2,3}$) were relative to the operations performed by a front-end loader. Silt content (S) and duration of material in storage (D) were also correction parameters. Because these factors were based on both limited test data data and engineering judgment, a "D" rating was assigned.

Emissions for cement loading, Source 21, were obtained from Reference 4. The emissions were based on tests of mechanical unloading of cement to a hopper and subsequent transport of cement by enclosed bucket elevator to elevated bins with a fabric sock over the bin vent. This emission rate was estimated to approximate truck, rail, or barge loadout, and was given an "E" rating.

Emissions Calculated from Observations and Source Reported Data

Emission rates for the remaining sources were determined by engineering judgment using observations made during plant visits and a detailed emissions inventory. The emissions inventory forms were received from a representative Portland cement producing facility. Data were presented showing controlled emissions from many potential fugitive particulate emission sources. The emission rates were based on stack tests of the control devices. Emission factors were then calculated using the reported emissions, control device efficiencies, and plant production. Consequently, the emission factors derived from these forms were rated "D" or "E", depending on the amount of alteration and engineering judgment that was necessary.

The first sources for which emissions were calculated in this manner were clinker/gypsum outfall to storage, storage, and load-out from storage, Sources 16, 17, and 18.

At the plant for which emissions data were obtained, these operations occurred in a totally enclosed building with a vent to a baghouse. Knowing the annual emissions from the baghouse, the amount of clinker handled per year, and the efficiency of the baghouse, the uncontrolled emissions were calculated to be 10 lb/ton. From observations during plant visits, it was judged that emissions from uncontrolled clinker storage could be quite significant, but that an average emission rate would be less than this value. Therefore, a range of 5 to 10 lb/ton was selected as the uncontrolled fugitive emission rate. This rate also assumes a partially enclosed structure - open on both ends with a roof. These emissions were assigned an "E" rating because of the engineering judgment involved.

Emissions were next calculated for raw material outfall to storage, storage, and transfer from storage to conveyor (via clamshell), Sources 7, 8, and 9. Engineering judgment alone was used for these sources since emissions data were not available. It was observed during plant visits that the operations involving raw materials were not as dusty as those where clinker was handled. Therefore, it was estimated that emissions from raw materials storage were 25 percent of the emissions from clinker storage. This results in an emission factor of 1.25 to 2.5 lb/ton. Since these factors were based on engineering judgment, they were given an "E" rating.

Fugitive emissions from cement finish grinding, Source 19, occur through leaks from the feed and discharge exhaust systems. Controlled emissions from the grinding mills were calculated from the emissions inventory data to equal approximately 0.1 lb/ton. It was estimated that the same amount also escapes from the hood pick-up systems at the feed and discharge points and from leaks in the mill. Being an engineering judgment, this factor was given an "E" rating.

Based on the emissions calculated for the finish mill and visual observations during plant visits, fugitive emissions from the raw grinding mill feed and discharge exhaust pick-up systems, Source 10, were judged to be also 0.1 lb/ton. This engineering estimate was given an "E" rating.

Raw material blending and storage, Sources 11 and 12, were estimated to have one-half the amount of fugitive emissions as that emitted by the raw grinding mill. This factor was based on plant observations and was assigned a reliability rating of "E".

Emissions due to transfer of coal from the storage pile to the grinding mill, Source 14, were derived from observations at plant visits and data contained in Reference 1. An emission rate for coal conveying and transfer at a coal mine is given in Reference 1 as 0.2 lb/ton. However, during plant visits it was observed that the emissions could be negligible from this operation. Therefore, this range was used for the factors. A reliability rating of "D" was selected since both engineering judgment and an emission factor specifically for coal conveying were used.

Leakage of coal from the grinding mills, Source 15, was observed during plant visits to be negligible. This engineering judgment was given an "E" rating.

Cement storage silos, Source 20, were found to be almost exclusively controlled by fabric filters. Emissions, therefore, were considered negligible from this source and an "E" rating was assigned.

Based on the emission inventory data, fabric filter controls for cement packaging, Source 22, were calculated to emit 0.01 lb/ton. It was estimated that emissions escaping capture by the control system could be equal to or less than this value. Therefore, the range of fugitive emissions was from negligible to 0.01 lb/ton, and was given an "E" rating.

Model Plant Inventory

The example plant inventory for Portland cement as shown in Table 1 presents potential fugitive emission quantities from the various uncontrolled sources within the process. The inventory represents a plant which produces

443,968 tons of Portland cement per year. The plant inventory is not meant to display a typical plant, but merely an example application of the uncontrolled fugitive emission factors.

REFERENCES

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2. Compilation of Air Pollutant Emission Factors, AP-42. U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina.

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4. Personal communication to John M. Zoller, PEDCo Environmental, Inc., from T.R. Blackwood, Monsanto Research Corporation, Dayton Laboratory, 1515 Nicholas Road, Dayton, Ohio. October 18, 1976.

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6. Cross, F.L., Jr., and Forehand, G.D. Air Pollution Emissions from Bulk Loading Facilities, Volume 6, Environmental Nomograph Series. Technomic Publishing Co., Inc., Westport, Connecticut, 1975. pp. 3-4.

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APPENDIX A

IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS

This appendix contains the remaining fugitive emission factor tables prepared for the guidance document. Note that these tables are presented as prepared for the guidance document. Table, section, and reference numbers refer to that document. These tables are presented to allow rapid dissemination of the information developed in that project.

Tables are presented for the following industries or processes: coke manufacturing; iron production; steel production; primary aluminum production; primary copper smelters; primary lead smelters; primary zinc production; secondary copper, brass/bronze production; foundries; minerals extraction and beneficiation; grain elevators; lime production; concrete batching; asphaltic concrete production; and lumber and furniture industry.

Table 2-9. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR COKE MANUFACTURING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Coal unloading	0.2 kg/Mg coal unloaded[a] (0.4 lb/ton)	E	Coal charged 1,542,500 (1,699,800)	309 (340)
2. Coal storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[b] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded onto pile$\left.\right)$	D	Coal loaded 1,550,000 (1,708,100)	62 (68)
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[b] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored$\left.\right)$	D	Coal stored 1,550,000 (1,708,100)	134 (148)
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[b] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out$\left.\right)$	D	Coal load out 1,550,000 (1,708,100)	81 (87)
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2} \frac{D}{90}$ kg/Mg material stored[b] $\left(\frac{(0.11)(S/1.5)}{(PE/100)^2} \frac{D}{90}\right.$ lb/ton material stored$\left.\right)$	D	Coal stored 1,550,000 (1,708,100)	227 (250)
3. Coal conveying and transfer	0.02-0.48 kg/Mg coal charged[c] (0.04-0.96 lb/ton)	E	Coal charged 1,542,500 (1,699,800)	231 (250)
4. Coal pulverizing and screening	d			d

Table 2-9 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR COKE MANUFACTURING

Source of IPPPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
5. Coal charging	0.5-5.0 kg/Mg coal charged[e,f,g,h] (1.0-10.0 lb/ton)	C	Coal charged 1,542,500 (1,699,800)	4,242 (4,674)
6. Coking (door leakage)	0.20-0.45 kg/Mg coal charged[e,f,i] (0.40-0.90 lb/ton)	C	Coal charged 1,542,500 (1,699,800)	501 (552)
7. Pushing	See Table 2-10		Coal charged 1,542,500 (1,699,800)	
8. Quenching	Clean water: 0.6 kg/Mg coke produced[j] (1.2 lb/ton) Highly contaminated water: 1.0-3.0 kg/Mg coke produced[j] (2.0-6.0 lb/ton)	C C	Coke produced 1,000,000 (1,102,000)	600 (660)
9. Coke handling	0.012-0.065 kg/Mg coke produced[k] (0.023-0.13 lb/ton)	E	Sized coke produced 1,000,000 (1,102,000)	38 (42)

[a] Coal hopper car unloading emission factor as developed in Section 2.1.2.

[b] For complete development of this emission factor refer to Section 2.1.4. For this example it was assumed that S = 4.0, D = 90, PE = 100, $K_1 = 0.75$, $K_2 = 0.5$, and $K_3 = 0.78$. Reference 4.

[c] Coal conveying and transfer emission factor as developed in Section 2.1.1. Reference 5.

[d] Included in coal handling and transfer emission factor.

[e] Reference 6.

[f] Reference 7.

[g] Reference 2.

[h] Reference 8.

[i] Reference 9.

[j] Personal communication with Carl Edlund, U.S. Environmental Protection Agency, Division of Stationary Source Enforcement, Washington, D.C., March 11, 1977. Emissions are for quench towers with baffles.

[k] Coke conveying and transfer emission factor as developed in Section 2.1.1.

Table 2-10. PUSHING EMISSION FACTORS

kg/Mg coal charged (lb/ton coal charged)

Degree of greenness	Shed[a]	Travelling hood[b]	Direct-uncaptured plume[b]
Green coke	$0.32^{h} - 0.5^{i}$ (0.65 - 1.0)	$1.0^{i} - 1.8^{d}$ (2.1 - 3.5)	$1.5 - 2.0^{e}$ (3 - 4)
Moderately green	0.28^{h} (0.57)	1.65^{d} (2.3)	1.0^{c} (2.1)
Cleanly pushed coke	$0.17^{f,g}$ (0.35)	0.75^{d} (1.5)	$0.19^{e} - 0.26^{c}$ (0.38 - 0.52)

[a] Includes most of travel emissions.

[b] Does not include travel emissions.

[c] Reference 11.

[d] Reference 12.

[e] Reference 13.

[f] Reference 14.

[g] Reference 15.

[h] Reference 16 and 28.

[i] Reference 17.

Table 2-12. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR IRON PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
1. Ship or railroad car unloading				
Iron ore - ship unloading Iron ore - rail unloading	Iron ore 0.01-0.015 kg/Mg unloaded[a] (0.02-0.03 lb/ton unloaded)	E	Iron ore unloaded 1,680,300 (1,848,300)	21 (23)
Limestone - ship unloading Limestone - rail unloading	Limestone 0.1 kg/Mg unloaded (0.2 lb/ton unloaded)	E	Limestone unloaded 248,565 (273,422)	25 (27)
2. Iron ore storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[b] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded onto pile$\left.\right)$	D	Iron ore loaded 1,680,300 (1,848,300)	218 (240)
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[b] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored$\left.\right)$	D	Iron ore stored 1,680,300 (1,848,300)	85 (94)
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[b] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out$\left.\right)$	D	Iron ore loaded out 1,680,300 (1,848,300)	364 (400)
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[b] $\left(\frac{(0.11)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}\right.$ lb/ton material stored$\left.\right)$	D	Iron ore stored 1,680,300 (1,848,300)	62 (68)

Table 2-12 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR IRON PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
3. Iron ore handling and transfer	1.0 kg/Mg ore handled[c] (2.0 lb/ton ore handled)	D	Iron ore 1,680,300 (1,848,300)	1,680 (1,848)
4. Limestone storage	b	D	Limestone 248,565 (273,422)	41 (45)
5. Limestone handling and transfer	0.1 kg/Mg limestone handled[d] (0.2 lb/ton limestone handled)	E	Limestone 248,565 (273,422)	25 (27)
6. Coke storage	b	D	Coke 586,613 (625,474)	56 (63)
7. Coke handling and transfer	See Section 2.2.1[e]			
8. Blast furnace flue dust storage	Negligible[f]	D	-	-
9. Blast furnace flue dust handling and transfer	0.15 kg/Mg flue dust[g] (0.3 lb/ton flue dust)	E	Flue dust 49,713 (54,684)	7 (8)
10. Sinter machine windbox discharge	Negligible[a,h]	-	-	-
11. Sinter machine discharge and screens	0.28-1.22 kg/Mg sinter[a,h] (0.55-2.45 lb/ton sinter)	E	Sinter 520,000 (570,000)	389 (427)
12. Sinter cooler	0.16-0.4 kg/Mg sinter[h,i] (0.32-0.8 lb/ton sinter)	E	Sinter 520,000 (570,000)	145 (160)

Table 2-12 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR IRON PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
13. Sinter storage	b	D	Sinter 44,000 (48,000)	7 (8)
14. Sinter handling and transfer	0.2 kg/Mg sinter[j] (0.4 lb/ton sinter)	E	Sinter 520,000 (570,000)	104 (114)
15. Blast furnace charging	Negligible	E	-	-
16. Blast furnace upsets (slips)	0.0019-0.019 kg/Mg iron produced[k] (0.0038-0.038 lb/ton iron produced)	E	Iron 994,260 (1,093,686)	10 (11)
17. Blast furnace tapping - iron	0.15-0.46 kg/Mg iron produced[k,l] (0.3-0.92 lb/ton iron produced)	E	Iron 994,260 (1,093,686)	423 (465)
	Model values: 0.39-0.49 kg/Mg iron produced[k,l] (0.78-0.92 lb/ton iron produced)	D	-	-
18. Blast furnace tapping - slag	l	-	-	l
19. Slag handling	0.01-0.05 kg/Mg slag[n] (0.02-0.1 lb/ton slag)	C	Slag 298,278 (328,106)	9 (10)
20. Slag storage	b	B	Slag 298,278 (328,106)	49 (54)
21. Slag crushing	1.0 kg/Mg crushed[o] (2.0 lb/ton crushed)	A	Slag 298,278 (328,106)	298[o] (328)

Table 2-12 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR IRON PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)

[a] Emission factor range for iron ore unloading (taconite pellets) derived from data presented in Section 2.1.2. Emission factor for limestone unloading also derived from data presented in Section 2.1.2 assuming 50 percent of coal unloading emission factor.

[b] For complete development of this emission factor, refer to Section 2.1.4. For sources 2, 6, and 20 refer to section 2.1.4 for values for variables in formulas except for D which was assumed to equal 90. For source 4 it was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Reference 1.

[c] Reference 2.

[d] Engineering judgment, assumed 50% of coal handling emissions as reported in Reference 3.

[e] Emissions identified and included in Section 2.2.1. Additional emission factor of 0.055 Kg/Mg (0.11 lb/ton) pig iron produced reported in Reference 3.

[f] Blast furnace flue dust is normally handled in a closed system and so a negligible source.

[g] Engineering judgment, assumed equal to sand handling emissions as reported in Reference 3.

[h] Reference 4.

[i] Reference 5.

[j] Engineering judgment, assumed equal to coal handling emissions as reported in Reference 3.

[k] Reference 6.

[l] Reference 7. Emissions for source 18 included in emissions from source 17.

[m] Emission for slag tapping included in iron tapping emission factor.

[n] Engineering judgment, assumed equal to coke handling emission range as described in Section 2.1.1.

[o] Estimated based on crushed stone emission factors for primary and secondary crushers in AP-42 (Reference 3). Note that approximately 65 percent of these emissions will settle out in the plant.

Table 2-14. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR STEEL PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
1. Scrap steel unloading, transfer and storage	Negligible	E		
2. Flux material unloading, transfer, and storage	Negligible	E		
3. Molten pig iron transfer from torpedos to charge ladles (hot metal reladling)	0.028-0.12 kg/Mg hot metal[a,b,c] (0.056-0.25 lb/ton hot metal)	D	Hot pig iron 3,178,000 (3,500,000)	235 (268)
4. Basic oxygen furnace - roof monitor (total)	0.08-0.6 kg/Mg steel[b,c,d,e] (0.15-1.2 lb/ton steel) also: E (lb/ton) = $1.09e^{0.0083P}$ where P = BOF capacity tons[f]	D	Steel produced 1,816,000 (2,000,000)	617 (675)
4a. Charging	0.15-0.20 kg/Mg hot metal poured[b] (0.3-0.4 lb/ton hot metal)	D		
4b. Leakage	Negligible[b]	E		
4c. Tapping-steel	0.07-0.15 kg/Mg steel tapped[b] (0.15-0.3 lb/ton steel tapped)	D		
4d. Tapping-slag	[g]			
5. Open hearth furnace - roof monitor (total)	0.05-0.20 kg/Mg steel[c,d,e,h] (0.1-0.39 lb/ton steel)	D	Steel produced 635,600 (700,000)	79 (86)
5a. Charging	[i]			
5b. Leakage	[i]			
5c. Tapping-steel	[i]			
5d. Tapping-slag	[i]			

Table 2-14 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR STEEL PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
6. Electric arc furnace - roof monitor (total)	0.09-1.5 kg/Mg steel[c,e,h,l] (0.18-3.0 lb/ton steel) Carbon steel: 1.5 kg/Mg steel (3.0 lb/ton) Alloy steel: 0.75 kg/Mg steel (1.5 lb/ton)	C	Steel produced (≈50% carbon steel) 454,000 (500,000)	511 (563)
6a. Charging	j			
6b. Leakage	j			
6c. Tapping-steel	j			
6d. Tapping-slag	j			
7. Ingot casting	0.014-0.06 kg/Mg steel[k] (0.028-0.12 lb/ton)	E	Steel produced 2,905,600 (3,200,000)	108 (118)
8. Molten steel reladling	0.014-0.06 kg/Mg steel[k] (0.028-0.12 lb/ton steel)	E	Steel produced 1,360,000 (1,500,000)	50 (56)
9. Scarfing	0.0055 kg/Mg steel[l] (0.011 lb/ton steel)	C	Steel produced 907,000 (1,000,000)	5 (5)

[a] Reference 2.

[b] Reference 3.

[c] Reference 4.

[d] Reference 5.

[e] Reference 6.

[f] Reference 7.

[g] Emissions included with steel tapping emission factor.

[h] Reference 8.

[i] Emissions included with total open hearth building emission factor.

[j] Emissions included with total electric furnace emission factor.

[k] Engineering judgment, assumed to be 50 percent of the hot metal reladling emission factor because of the lower carbon content of steel.

[l] Reference 24.

Table 2-16. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY ALUMINUM PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Material handling	5.0 kg/Mg of aluminum produced[a,b] (10 lb/ton)	E	Aluminum produced 200,000 (220,400)	1,000 (1,102)
2. Anode baking	1.0-5.0 (1.5) kg/Mg of aluminum[b] produced[c] (3.0 lb/ton)	D	Aluminum produced 200,000 (220,400)	300 (330)
3. Electrolytic reduction cell				
3a. Prebaked	0.75-6.7 kg/Mg of aluminum produced[c] (1.5-13.4 lb/ton)	D	Aluminum produced 200,000 (220,400)	745 (821)
3b. VSS Soderberg	13.1 kg/Mg of aluminum produced[c] (26.2 lb/ton)	D		
3c. HSS Soderberg	0.75-10.8 kg/Mg of aluminum produced[c] (1.5-21.6 lb/ton)	D		
4. Refining	1.25 kg/Mg of aluminum produced[d] (2.5 lb/ton)	E	Aluminum produced 200,000 (220,000)	250 (275)

[a] Includes unloading conveying, crushing, screening, mixing, and green anode or paste preparation. Individual emission rates are not available. Most of these sources are enclosed/vented through a particulate control device.

[b] Reference 1 and 2.

[c] Reference 2 and 3. Includes charging, tapping, and anode replacement.

[d] No data available. Estimate based on the emission factor in Reference 1, assuming 95 percent hood capture efficiency.

Table 2-21. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY COPPER SMELTERS

			Model plant fugitive emission inventory	
Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Unloading and handling of ore concentrate	5 kg/Mg material handled[a,b] (10 lb/ton)	E	Ore concentrate 305,140 (336,165)	1,526 (1,681)
2. Ore concentrate storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[c] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\text{ lb/ton}\right)$	D	Ore concentrate loaded 305,140 (336,165)	6 (7)
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[c] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\text{ lb/ton}\right)$	D	Ore concentrate stored 305,140 (336,165)	20 (22)
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[c] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\text{ lb/ton}\right)$	D	Ore concentrate loaded out 305,140 (336,165)	8 (9)
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[c] $\left(\frac{(0.11)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}\text{ lb/ton}\right)$	D	Ore concentrate stored 305,140 (336,165)	17 (18)

Table 2-21 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY COPPER SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
3. Limestone flux unloading and handling	b			b
4. Limestone flux storage	c	D	Limestone flux 138,700 (152,570)	23 (25)
5. Roaster charging	11.5 kg/Mg copper produced[d,e] (23 lb/ton)	E	Copper produced 90,478 (99,645)	1,040 (1,146)
6. Roaster leakage	e			e
7. Calcine transfer	e			e
8. Charging reverberatory furnace	4.15-4.35 kg/Mg copper produced[f,g,h] (8.3-8.7 lb/ton)	E	Copper produced 90,478 (99,645)	385 (423)
9. Tapping of reverberatory	h			g
10. Reverberatory furnace leakage	h			g

Table 2-21 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY COPPER SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
11. Slag tapping	h			g
12. Converter charging	1.6-8.85 kg/Mg copper produced[d,i,j] (3.3-17.7 lb/ton)	E	Copper produced 90,478 (99,645)	545 (600)
13. Converter leakage	j			i
14. Slag tapping from converter	j			i
15. Blister copper tapping	j			i
16. Blister copper transfer	j			i
17. Charging blister copper to fire refining furnace	0.5-1.4 kg/Mg copper produced[i,m] (1.0-2.8 lb/ton)	E	Copper produced 90,478 (99,645)	86 (95)
18. Copper tapping and casting	1.26 kg/Mg copper produced[f,k] (2.52 lb/ton)	E	Copper produced 90,478 (99,645)	114 (126)
19. Slag tapping and handling	k			j

[a] Reference 1 also includes slag handling.

[b] Emission from limestone unloading and handling included in emission factor for ore unloading and handling.

[c] For complete development of this emission factor, refer to Section 2.1.4. The emission factor for source 4 is the same as source 2. For these examples it was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Reference 2.

[d] Based on material balance using same percentage as estimated for SO_2 emissions from reference 3.

[e] Emissions from roaster leakage and transfer are included in emission factor for roaster charging.

[f] Reference 4.

[g] Lower value of range is for plants with roaster, high value for plants without roaster.

[h] Emissions from reverberatory tapping and leakage are included in emission factor for reverberatory charging.

[i] Reference 5.

[j] Emissions from converter leakage and tapping, and blister copper transfer are included with converter charging emission factor.

[k] Emissions from slag to tapping are included in casting building emissions.

[l] Engineering judgment, assumed approximately equal to 25 percent of the reverberatory furnace fugitive emissions.

[m] Reference 13.

Table 2-24. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY LEAD SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, metric tons/year (tons/year)	Uncontrolled emissions metric tons/yr (tons/yr)
1. Railroad car and truck unloading				
Limestone	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	Limestone unloaded 79,445 (87,390)	8 (9)
Silica sand	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	Silica unloaded 3,500 (3,850)	0.38 (0.41)
Lead ore concentrate	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	Lead ore unloaded 317,782 (349,560)	34 (37)
Iron ore	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	Iron ore unloaded 45,000 (49,500)	5 (6)
Coke	0.2 kg/Mg unloaded[a] (0.4 lb/ton unloaded)	E	Coke unloaded 94,494 (103,943)	19 (21)
2. Blast furnace flue dust				
2a. Storage	Negligible[b]	E	-	b
2b. Handling and transfer	Negligible[b]	E	-	b
3. Limestone				
3a. Storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[c] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded onto pile$\left.\right)$	D	Limestone loaded 79,445 (87,390)	2 (2)

Table 2-24 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY LEAD SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[c]	D	Limestone stored 79,445 (87,390)	5 (6)
	$\left(\frac{(0.04)(K_2)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored$\left.\right)$			
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[c]	D	Limestone loaded out 79,445 (87,390)	2 (2)
	$\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out$\left.\right)$			
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[c]	D	Limestone stored 79,445 (87,390)	4 (4)
	$\left(\frac{(0.011)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}\right.$ lb/ton material stored$\left.\right)$			
3b. Handling and transfer	0.1 kg/Mg limestone handled[d] (0.2 lb/ton limestone handled)	E	Limestone handled 79,445 (87,390)	8 (9)
4. Silica sand				
4a. Storage	c	D	Silica stored 3,500 (3,850)	1 (1)
4b. Handling and transfer	0.15 kg/Mg silica sand handled[e] (0.3 lb/ton silica sand handled)	E	Silica handled 3,500 (3,850)	1 (1)

Table 2-24 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY LEAD SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
5. Lead ore concentrate				
5a. Storage	c	D	Concentrate stored 317,782 (349,560)	52 (57)
5b. Handling and transfer	0.82-2.5 kg/Mg handled[f] (1.64-5.0 lb/ton handled)	E	Concentrate handled 317,782 (349,560)	528 (580)
6. Iron ore				
6a. Storage	c	D	Ore stored 45,000 (49,500)	29 (32)
6b. Handling and transfer	1.0 kg/Mg iron ore handled[g] (2.0 lb/ton iron ore handled)	E	Ore handled 45,000 (49,000)	45 (49)
7. Coke				
7a. Storage	c	D	Coke stored 94,494 (103,943)	7 (8)
7b. Handling and transfer	0.06-0.1 kg/Mg coke handled[h,i] (0.13-3.39 lb/ton coke handled)	E	Coke handled 94,494 (103,943)	8 (9)

Table 2-24 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY LEAD SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
8. Mixing and pelletizing	0.57-1.70 kg/Mg lead product[j] (1.13-3.39 lb/ton lead product)	D	Lead produced 200,000 (220,000)	227 (247)
9. Sinter machine	0.12-0.55 kg/Mg sinter[k] (0.25-1.1 lb/ton sinter)	E	Sinter produced 349,979 (384,977)	117 (130)
10. Sinter return handling	2.25-6.75 kg/Mg sinter[j] (4.5-13.5 lb/ton sinter)	D	Sinter produced 349,979 (384,977)	1,575 (1,732)
11. Sinter machine discharge and screens	0.28-1.22 kg/Mg sinter[k] (0.55-2.45 lb/ton sinter)	E	Sinter produced 349,979 (384,977)	262 (289)
12. Sinter crushing	l			l
13. Sinter transfer to dump area	0.05-0.15 kg/Mg sinter transfered[j] (0.10-0.30 lb/ton sinter transfered)	D	Sinter transfered 349,979 (384,977)	35 (38)
14. Sinter product dump area	0.0025-0.0075 kg/Mg sinter dumped[j] (0.005-0.015 lb/ton sinter dumped)	D	Sinter dumped 349,979 (384,977)	2 (2)

Table 2-24 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY LEAD SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
15. Charge car or conveyor loading and transfer of sinter	0.13-0.38 kg/Mg charged[j] (0.25-0.75 lb/ton charged)	D	Blast furnace charge 477,226 (524,949)	122 (131)
16. Blast furnace - monitor (total)	0.04-0.12 kg/Mg lead produced[j,m] (0.08-0.23 lb/ton)	D	Lead produced 200,000 (220,000)	16 (17)
16a. Charging	m			m
16b. Blow condition	m			m
16c. Upset[n]	3.5-11.5 kq/Mg lead produced[j,m] (7.0-23.0 lb/ton)	D		o
16d. Tapping	m			m
17. Lead pouring to ladle and transfer	0.47 kg/Mg lead produced[f] (0.93 lb/ton lead produced)	E	Lead produced 200,000 (220,000)	94 (102)
18. Slag pouring	p			p
19. Slag cooling	0.24 kg/Mg lead produced[q] (0.47 lb/ton lead produced)	E	Lead produced 200,000 (220,000)	48 (52)
20. Slag granulator and slag piling	Negligible[r]	E	Slag crushed 200,000 (220,000)	200 (220)
21. Zinc fuming furnace vents	1.15-3.45 kg/Mg lead[j] (2.3-6.9 lbs/ton lead)	D	Lead produced 200,000 (220,000)	460 (506)
22. Dross kettle	0.12-0.36 kg/Mg lead[j] (0.24-0.72 lb/ton lead)	D	Lead produced 200,000 (220,000)	48 (53)

Table 2-24 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY LEAD SMELTERS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
23. Reverberatory furnace leakage	0.75-2.25 kg/Mg lead[j] (1.5-4.5 lb/ton lead)	D	Lead produced 200,000 (220,000)	300 (330)
24. Silver retort building	0.45-1.35 kg/Mg lead[j] (0.9-2.7 lb/ton lead)	D	Lead produced 200,000 (220,000)	180 (198)
25. Lead casting	0.22-0.66 kg/Mg lead[j] 0.43-1.30 lb/ton lead)	D	Lead produced 200,000 (200,000)	88 (96)

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[a] Engineering judgement based on data presented in Section 2.1.2; emission range derived using emission factors for unloading of Taconite pellets and coal/hopper car; emission factor for coke derived from coal unloading emission factor only.

[b] Engineering judgement, assumed enclosed handling and storage or direct recycle to system.

[c] For complete development of this emission factor, refer to Section 2.1.4. The emission factor for sources 4a, 5a, 6a, and 7a are the same as source 3a. For sources 3a, 4a, and 5a it was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Values for sources 6 and 7 can be found in Section 2.1.4. Reference 1.

[d] Engineering judgment, assumed 50 percent of coal handling emissions as reported in Reference 2.

[e] Engineering judgment based on aggregate storage pile emission factors in Reference 2.

[f] Reference 3.

[g] Reference 4.

[h] Engineering judgment; calculated from emission factor (0.055 kg/Mg of iron) given in Reference 5.

[i] Reference 6.

[j] Reference 7.

[k] Engineering judgment using steel sinter machine leakage emission factor given in Reference 8 and 9.

[l] Emissions for sinter crushing included in emissions from sinter machine discharge and screens.

[m] Emissions for charging, blow condition, and tapping included in total.

[n] Emission factor for upset not considered part of normal operating conditions and is not included in emission factor for the blast furnace roof monitor.

[o] Emissions for blast furnace upset are not included in model plant inventory.

[p] Emissions for slag pouring included in lead pouring to ladle and transfer emission.

[q] Engineering judgment; estimated to be one half the magnitude of pouring and ladling operations (source number 17).

[r] Granulated slag is wet and therefore most likely not a source of fugitive emissions. Reference 10.

Table 2-27. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Railroad car or truck unloading				
1a. Zinc ore concentrate	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	Zinc ore concentrate 195,447 (214,992)	21 (23)
1b. Sand	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	Sand 1,613 (1,774)	0.17 (0.19)
1c. Coke	0.2 kg/Mg unloaded[a] (0.4 lb/ton unloaded)	E	Coke 5,734 (6,307)	1 (1)
2. Zinc ore concentrate				
2a. Storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[b] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded onto pile)	D	Ore concentrate loaded 195,447 (214,992)	4 (4)
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[b] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored)	D	Ore concentrate stored 195,447 (214,992)	13 (14)
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[b] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out)	D	Ore concentrate loaded out 195,447 (214,992)	5 (5)

Table 2-27 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[b] ($\frac{(0.11)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ lb/ton material stored)	D	Ore concentrate loaded out 195,447 (214,992)	10 (11)
2b. Handling and transfer	0.82-2.5 kg/Mg handled[c] (1.64-5.0 lb/ton handled)	E	Ore concentrate handled 195,447 (214,992)	324 (356)
3. Sand				
3a. Stored	b	D	Sand 1,613 (1,774)	0.27 (0.29)
3b. Handling and transfer	0.15 kg/Mg handled[d] (0.3 lb/ton handled)	D	Sand 1,613 (1,774)	0.24 (0.26)
4. Coke				
4a. Storage	b	D	Coke 5,734 (6,307)	1 (1)
4b. Handling and transfer	0.06-0.1 kg/Mg handled[e,f] (0.12-0.2 lb/ton handled)	D	Coke 5,734 (6,307)	0.46 (0.50)

Table 2-27 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
5. Sinter machine windbox discharge	0.12-0.55 kg/Mg sinter[d,g] (0.25-1.1 lb/ton sinter)	E	Sinter 70,788 (78,867)	24 (26)
6. Sinter machine discharge and screens	0.28-1.22 kg/Mg sinter[g,h] (0.55-2.45 lb/ton sinter)	E	Sinter 70,788 (78,867)	53 (59)
7. Coke-sinter mixer	i			g
8. Retort furnace building	1.0-2.0 kg/Mg of zinc[j] (2.0-4.0 lbs/ton of zinc)	E	Zinc 68,100 (75,000)	61 (68)
8a. Retort furnace tapping	k			i
8b. Retort furnace residue discharge and cooling	0.25-1.0 kg/Mg of zinc[l] (0.5-2.0 lb/ton of zinc)	E	Zinc 68,100 (75,000)	43 (47)
8c. Retort furnace upset	2.5-5 kg/Mg zinc[m] (5-10 lbs/ton zinc)	E	Zinc 68,100 (75,000)	
9. Zinc casting	1.26 kg/Mg zinc[n] (2.52 lb/ton zinc)	E	Zinc 68,100 (75,000)	86 (95)

Table 2-27 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR PRIMARY ZINC PRODUCTION

Source of IPPPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)

[a] Estimate based on data presented in Section 2.1.2; emission range derived using emission factors for unloading of Taconite pellets and coal/hopper car; emission factor for coal derived from coal unloading factor only.

[b] For complete development of this emission factor, refer to Section 2.1.4. The emission factor for sources 3a and 4a are the same as source 2. For sources 2a and 3a it was assumed that $S = 1.5$, $D = 90$, $PE = 100$, and K_1, K_2, and $K_3 = 1$. Values for source 4 can be found in Section 2.1.4. Reference 2.

[c] Engineering judgment assuming that fugitive emission factors given for lead ore concentrate (Reference 3) to be similar to those for zinc ore concentrate.

[d] Reference 4.

[e] Engineering judgment based on 50% of emission factor given for coal in Reference 4.

[f] Reference 5.

[g] Engineering judgment assuming that fugitive emission factors given for sintering machine in iron production (Reference 6) is similar for sintering in zinc production.

[h] Reference 7.

[i] Emissions from coke-sinter mixer included in emission factor for sinter machine discharge and screens (emission source 6).

[j] Engineering judgment using emission factor from retort building in primary lead smelting (Reference 8).

[k] Emissions from retort furnace tapping included in emission factor for retort building total (emission source 8).

[l] Engineering judgment based on observation of retort residue discharging and cooling at a secondary zinc smelter which is similar to primary zinc production.

[m] Engineering judgment using emission factor for primary copper smelting given in Reference 9. Not considered part of ordinary operations. Reference 10.

[n] Engineering judgment assuming fugitive emissions from zinc casting equal to fugitive emission for copper casting given in reference 11.

Table 2-29. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY ALUMINUM PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Sweating furnace	0.36 kg/Mg metal processed[a] (0.72 lb/ton metal processed)	E	Scrap processed 2,727 (3,000)	1 (1)
1a. Charging	b			
1b. Tapping	b			
2. Crushing and screening scrap metal	Negligible[c]	E		Negligible
3. Chip (rotary) dryer	0.36 kg/Mg metal dried[d] (0.72 lb/ton metal dried)	E	Metal dried 1,136 (1,250)	5 (6)
4. Smelting (reverberatory) furnace	0.11 kg/Mg metal processed[a] (0.22 lb/ton metal processed)	E	Metal processed 4,546 (5,000)	1 (1)
4a. Charging	e			
4b. Tapping	e			
5. Smelting (crucible) furnace	0.05 kg/Mg metal processed[a] (0.09 lb/ton metal processed)	E	-	-
5a. Charging	f			
5b. Tapping	f			
6. Smelting (induction) furnace	0.05 kg/Mg metal processed[g] (0.09 lb/ton metal processed)	E	-	-
6a. Charging	h			
6b. Tapping	h			

Table 2-29 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY ALUMINUM PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
7. Fluxing (chlorination)	25 kg/Mg chlorine used[a] (50 lb/ton chlorine used)	E	Chlorine used[i] 455 (500)	12 (13)
8. Hot dross handling and cooling	0.11 kg/Mg metal processed[j] (0.22 lb/ton metal processed)	E	Metal processed 4,546 (5,000)	1 (1)
9. Pouring hot metal into molds or crucible	Negligible[k]	E	-	Negligible

[a] Engineering judgement, assume 5% of uncontrolled stack emissions as reported in Reference 4, p. 7.8-1.

[b] Emissions included with total sweating furnace emission factor.

[c] Based on engineering judgement.

[d] Assume uncontrolled fugitive emissions are equal to the emissions from the sweating furnace.

[e] Emissions included with total reverberatory furnace emission factor.

[f] Emissions included with total crucible furnace emission factor.

[g] Assume uncontrolled fugitive emissions are equal to the emissions from the crucible furnace.

[h] Emissions included with total induction furnace emission factor.

[i] Assume that the amount of fluxing agent used is 10% of the weight of the metal processed in the reverberatory furnace (Reference 1, p. 286).

[j] Assume that the emissions are equal to the emissions from the reverberatory furnace.

[k] Emissions are negligible as reported in Reference 1, p. 285.

Table 2-32. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY LEAD SMELTING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
1. Railroad car and truck			Coke unloaded	
Coke	0.2 kg/Mg unloaded[a] (0.4 lb/ton unloaded)	E	3,141 (3,455)	0.63 (0.69)
Limestone			Limestone unloaded	
	0.015-0.2 kg/Mg unloaded[a] (0.03-0.4 lb/ton unloaded)	E	1,713 (1,884)	0.18 (0.20)
Lead scrap	Negligible	E	-	-
Iron scrap	Negligible	E	-	-
2. Coke				
2a Storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[b] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material onto pile$\left.\right)$	D	Coke loaded 3,141 (3,455)	negligible
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[b] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored$\left.\right)$	D	Coke stored 3,141 (3,455)	negligible
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[b] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out$\left.\right)$	D	Coke loaded out 3,141 (3,455)	negligible

Table 2-32 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY LEAD SMELTING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[b] $\left(\frac{(0.11)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}\right.$ lb/ton material stored$\left.\right)$	D	Coke stored 3,141 (3,455)	negligible
2b Handling and transfer	0.055-0.07 kg/Mg handled[c,d] (0.11-0.13 lb/ton handled)	D	Coke handled 3,141 (3,455)	0.20 (0.22)
3. Limestone				
3a Stored	b	D	Lime stored 1,713 (1,884)	negligible
3b Handling and transfer	0.1 kg/Mg limestone handled[e] (0.2 lb/ton limestone handled)	E	Limestone handled 1,713 (1,884)	negligible
4. Lead scrap				
4a Storage	Negligible	E	-	-
4b Handling and transfer	Negligible	E	-	-
5. Iron scrap				
5a Storage	Negligible	E	-	-
5b Handling and transfer	Negligible	E	-	-
6. Lead and iron scrap burning	0.5-1.0 kg/Mg scrap burned[f] (1.0-2.0 lb/ton scrap burned)	E	Total scrap burned 151,437 (166,580)	114 (125)
7. Sweating furnace (total)	0.8-1.75 kg/Mg charged[g] (1.6-3.5 lb/ton charged)	E	Material charged 137,670 (151,437)	176 (194)

Table 2-32 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY LEAD SMELTING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
7a Charging	h			h
7b Tapping	h			h
8. Reverberatory furnace (total)		E	Total charge	
	1.4-7.85 kg/Mg charged[g]	E	135,000	625
	(2.8-15.7 lb/ton charged)		(148,610)	(688)
8a Charging	i			i
8b Tapping	i			i
9. Blast or cupola furnace (total)			Total charge	
	6 kg/Mg charged[j]	E	57,100	343
	(12 lb/ton charged)		(62,810)	(377)
9a Charging	k			k
9b Lead tapping to holding pot	k			k
9c Slag tapping	k			k
10. Tapping of holding pot	k			k

Table 2-32 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY LEAD SMELTING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
11. Pot (kettle) furnace (total)	0.02 kg/Mg charged[g] (0.04 lb/ton charged)	C	Total charge 12,000 (13,200)	0.24 (0.26)
11a Charging	[l]			[l]
11b Tapping	[l]			[l]
12. Casting	0.44 kg/Mg lead cast[m] (0.87 lb/ton lead cast)	C	Lead cast 80,000 (88,000)	35 (38)

[a] Estimate based on data presented in Section 2.1.2; emission range derived using emission factors for unloading taconite pellets and coal/hopper car; emission factor for coke derived only from coal unloading emission factor.

[b] For complete development of this emission factor, refer to Section 2.1.4. The emission factor for source 3a is the same for source 2a. For source 3a it was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Values for source 2a can be found in Section 2.1.4. Reference 1.

[c] Reference 2.

[d] Reference 3.

[e] Engineering judgment, assumed 50 percent of coal handling emission reported for coal in Reference 4.

[f] Engineering judgment based on emission factor for zinc residual scrap (Reference 1) with 5 percent resulting in fugitive emissions.

[g] Engineering judgment based on lead sweating emission factor given in Reference 5 with 6 percent resulting in fugitive emissions.

[h] Fugitive emissions for charging and tapping included in emission for total sweating furnace operation (Source 7).

[i] Fugitive emissions for charging and tapping included in emission for total reverberatory furnace operation (Source 8).

[j] Engineering judgment based on emission factor given in Reference 6 with 5 percent resulting in fugitive emissions.

[k] Fugitive emissions for charging, lead tapping to holding pot, slag tapping, and tapping of holding pot included in emission factor for total blast furnace operation (Source 9).

[l] Fugitive emissions for charging and tapping included in emissions for total pot furnace operations (Source 11).

[m] Reference 7; fugitive emissions for primary lead casting assumed equal to fugitive emissions for secondary lead casting.

Table 2-34. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Crushing/screening of residue skimmings	0.5-3.8 kg/Mg crushed and screened[a] (1.0-7.6 lb/ton crushed and screened)	E	Residue skimmings crushed 2,877 (3,165)	6 (7)
2. Reverberatory sweat furnace (total)	Neg.-0.63 kg/Mg product[b] (Neg.-1.3 lb/ton product)	E	v	v
2a. Charging	c		v	v
2b. Tapping	c		v	v
3. Kettle (Pot) sweat furnace (total)	0.28 kg/Mg product[b] (0.56 lb/ton product	E	Metal produced 6,276 (6,904)	2 (2)
3a. Charging	d			d
3b. Tapping	d			d
4. Rotary sweat furnace (total)	0.28-0.63 kg/Mg product[e] (0.56-1.26 lb/ton product)	E	Residue skimmings 6,276 (6,904)	3 (3)
4a. Charging	f			f
4b. Tapping	f			f
5. Muffle sweat furnace (total)	0.27-0.8 kg/Mg zinc scrap charged[e] (0.54-1.6 lb/ton zinc scrap charged)	E	v	v
5a. Charging	g		v	v
5b. Tapping	g		v	v

Table 2-34 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
6. Electric resistance sweat furnace (total)	0.25 kg/Mg zinc scrap charged[e] (0.5 lb/ton zinc scrap charged)	E	v	v
6a. Charging	h		v	v
6b. Tapping	h		v	v
7. Hot metal transfer to melting furnaces	i			i
8. Crucible melting furnace (total)	0.0025 kg/Mg zinc produced[j] (0.005 lb/ton zinc produced)	E	Zinc produced 5,230 (5,753)	0.01 (0.01)
8a. Charging	k			k
8b. Tapping	k			k
9. Kettle (pot) melting furnace (total)	0.0025 kg/Mg zinc product[b] (0.005 lb/ton zinc produced)	E	v	v
9a. Charging	l		v	v
9b. Tapping	l		v	v
10. Reverberatory melting furnace (total)	0.0025 Kg/Mg zinc produced[e] (0.005 lb/ton zinc produced)	E	Zinc produced 5,230 (5,753)	0.01 (0.01)
10a. Charging	m			m
10b. Tapping	m			m

Table 2-34 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
11. Electric induction melting (total)	0.0025 kg/Mg zinc produced[e] (0.005 lb/ton zinc produced)	E	v	v
11a. Charging	n		v	v
11b. Tapping	n		v	v
12. Hot metal transfer to retort or alloying	i			i
13. Distillation retort and condenser (total)	1.18 kg/Mg zinc produced[o] (2.36 lb/ton zinc produced)	E	Zinc produced 5,475 (6,023)	6 (7)
13a. Charging distillation retort	p			p
13b. Leakage between retort condenser	Negligible	E	-	-
13c. Upset in condenser	2.5-5.0 kg/Mg zinc produced[q] (5.0-10 lb/ton zinc produced)	E	-	w
13d. Tapping	0.01-0.02 kg/Mg tapped[e,p] (0.02-0.04 lb/ton tapped)	E	p	p
14. Muffle distillation furnace and condenser	1.18 kg/Mg zinc produced[o] (2.36 lb/ton zinc produced)	E	Zinc produced 5,475 (6,023)	(6) (7)
14a. Charging muffle distillation furnace	r			r
14b. Leakage between furnace and condenser	Negligible	E	-	-

Table 2-34 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY ZINC PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
14c. Upset in condenser	2.5-5.0 kg/Mg zinc produced[s] (5.0-10.0 lb/ton zinc produced)	E		w
14d. Tapping	0.01-0.02 kg/Mg zinc tapped[t,r] (0.02-0.04 lb/ton tapped)	E		r
15. Alloying	u			u
16. Casting	0.005-0.01 kg/Mg zinc cast[e] (0.01-0.02 lb/ton zinc cast)	E	Zinc cast 10,950 (12,045)	0.08 (0.09)

[a] Reference 1.

[b] Engineering judgment based on emission factors given in references 1 and 2 assuming fugitive emissions to be equal to 5 percent of stack emissions. Ranges, when they appear, were derived from factors for clean and residual scrap.

[c] Emission included in total for Source 2.

[d] Emission included in total for Source 3.

[e] Engineering judgment based on stack emission factor given in Reference 1 assuming fugitive emissions to be equal to 5 percent of stack emissions.

[f] Emissions included in total for Source 4.

[g] Emissions included in total for Source 5.

[h] Emissions included in total for Source 6.

[i] Emissions included in emissions for individual furnace operations.

[j] Engineering judgment assuming fugitive emissions from crucible melting furnace to be equal to fugitive emissions from kettle (pot) melting furnace (Source 9).

[k] Emissions included in total for Source 8.

[l] Emissions included in total for Source 9.

[m] Emissions included in total for Source 10.

[n] Emissions included in total for Source 11.

[o] Engineering judgment based on emission factor given in Reference 2, assuming fugitive emissions to be equal to 5 percent of stack emissions.

[p] Emissions included in total for Source 13.

[q] Personal communication from J. P. Barnhart of W. J. Bullock, Inc. to Thomas Janssen. Personal estimation by J. P. Barnhart. This is not considered part of normal operating conditions.

[r] Emissions included in total for Source 14.

[s] Engineering judgment assuming upset conditions for Source 13c to be equal to that for Source 14c.

[t] Engineering judgment assuming tapping emissions for Source 13d equal to those for Source 14d.

[u] Alloying often takes place with the sweating or melting operations (Reference 1), however, if performed separately, it is an engineering judgment that fugitive emissions could range from negligible to as high as the emission factor given for iron innoculation in Section 2.5 of this report.

[v] Not included in emission inventory.

[w] Upset conditions are not considered part of normal operating conditions and therefore are not included in the emission inventory.

Table 2-36. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY COPPER, BRASS/BRONZE PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
1. Sweating furnace (total)	0.38 kg/Mg scrap charged[a] (0.76 lb/ton scrap charged)	E	Material charged 19,789 (21,768)	8 (9)
1a. Charging	b			b
1b. Tapping	b			b
2. Drying (total)	6.85 kg/Mg scrap dried[a] (13.7 lb/ton scrap dried)	E	n	n
2a. Charging	c		n	n
2b. Discharging	c		n	n
3. Insulation burning	6.9 kg/Mg scrap burned[d] (13.8 lb/ton scrap burned)	E	Scrap burned 38,462 (42,308)	265 (292)
4. Electric induction furnace (total)	0.025-0.07 kg/Mg scrap charged[e] (0.05-0.14 lb/ton scrap charged)	E	n	n
4a. Charging	f		n	n
4b. Tapping	f		n	n
5. Reverberatory furnace (total)	1.33-3.92 kg/Mg charged[g] (2.65-7.84 lb/ton charged)	E	Material charged 12,500 (13,750)	33 (36)
5a. Charging	0.6-1.48 kg/Mg charged[g,h] (1.2-2.95 lb/ton charged)	E	Material charged 12,500 (13,750)	13[h] (14)
5b. Tapping	0.01-0.025 kg/Mg charged[g,h] (0.02-0.05 lb/ton charged)	E	Material charged 12,500 (13,750)	0.2[h] (0.2)

Table 2-36 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY COPPER, BRASS/BRONZE PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
6. Rotary furnace (total)	0.75-3.68 kg/Mg charged[g] (1.5-7.35 lb/ton charged)	E	Material charged 13,700 (15,070)	30 (33)
6a. Charging	0.3 kg/Mg charged[g,i] (0.59 lb/ton charged)	E	Material charged 13,700 (15,070)	4[i] (4)
6b. Tapping	0.015-0.045 kg/Mg charged[g,i] (0.03-0.09 lb/ton charged)	E	Material charged 13,700 (15,070)	0.4[i] (0.4)
7. Crucible furnace (total)	0.16-0.32 kg/Mg charged[e] (0.32-0.64 lb/ton charged)	E	n	n
7a. Charging	j		n	n
7b. Tapping	j		n	n
8. Cupola (blast) furnace (total)	0.5-1.75 kg/Mg charged[k] (1.0-3.5 lb/ton charged)	E	Material charged 15,714 (17,286)	18 (19)
8a. Charging	l			l
8b. Tapping	l			l
9. Casting	0.005-0.01 kg/Mg cast[m] (0.01-0.02 lb/ton cast)	E	Metal cast 30,000 (33,000)	0.2 (0.2)

Table 2-36 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR SECONDARY COPPER, BRASS/BRONZE PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)

[a] Engineering judgement assuming that fugitive emissions are equal to 5 percent of stack emission factor given in Reference 1.

[b] Emissions included in total for source 1.

[c] Emissions included in total for source 2.

[d] Engineering judgement assuming that fugitive emissions are equal to 5 percent of stack emission factor given in Reference 2.

[e] Engineering judgement assuming that fugitive emissions are equal to 5 percent of stack emission factors given in References 2 and 3.

[f] Emissions included in total for source 4.

[g] Engineering judgement assuming that fugitive emissions are equal to 5 percent of stack emission data given in Reference 4.

[h] Emissions for tapping and charging also included in as part of the emission factor given for total (source 5).

[i] Emissions for tapping and charging also included in as part of the emission factor given for total (source 6).

[j] Emissions for charging and tapping included in total for source 7.

[k] Engineering judgement assuming that fugitive emissions are equal to 5 percent of the stack emission factor and data given in References 3 and 4.

[l] Emission for charging and tapping included total for source 8.

[m] Engineering judgement assuming fugitive emissions for zinc casting given in Section 2.4.3 to be equal to those for copper, brass, and bronze.

[n] Not included in emission inventory.

Table 2-39. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR FOUNDRIES

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Raw material receiving and storage				
1a Unloading	Coke unloading 0.2 kg/Mg coke[a] (0.4 lb/ton coke)	E	Coke 1,818 (2,000)	1 (1)
1b Storage				
Loading onto pile	$\frac{(0.02)(K_1)(S/1.5)}{(PE/100)^2}$ kg/Mg material onto pile[b] $\left(\frac{(0.04)(K_1)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded onto pile)	D	Coke loaded 1,818 (2,000)	negligible
Vehicular traffic	$\frac{(0.065)(K_2)(S/1.5)}{(PE/100)^2}$ kg/Mg material stored[b] $\left(\frac{(0.13)(K_2)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored)	D	Coke stored 1,818 (2,000)	negligible
Loading out	$\frac{(0.025)(K_3)(S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[b] $\left(\frac{(0.05)(K_3)(S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out)	D	Coke loaded out 1,818 (2,000)	negligible
Wind erosion	$\frac{(0.055)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}$ kg/Mg material stored[b] $\left(\frac{(0.11)(S/1.5)}{(PE/100)^2}\ \frac{D}{90}\right.$ lb/ton material stored)	D	Coke stored 1,818 (2,000)	negligible

Table 2-39 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR FOUNDRIES

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
2. Cupola furnace operation (charging, tapping, etc.)	0.05-1 kg/Mg iron[c] (0.1-2 lb/ton iron)	E	Iron castings 13,490 (14,840)	7
3. Crucible furnace operation (charging, tapping, etc.)	0.05-0.3 kg/Mg of metal processed[d] (0.1-0.6 lb/ton of metal processed)	E		
4. Electric arc furnace operation	2.5-5 kg/Mg of metal charged[e] (5.0-10 lb/ton of metal charged)	E		
	0.53-1.74 kg/Mg of steel[f,g] (1.05-3.48 lb/ton of steel)	E		
5. Open hearth furnace operation	0.05-0.45 kg/Mg of metal charged[c,h] (0.1-0.9 lb/ton of metal charged)	E		
6. Electric induction furnace operation[i]	1.0 kg/Mg of metal charged[e] (2.0 lb/ton of metal charged)	E		
	0.75 kg/Mg of iron[c] (1.5 lb/ton of iron)	E		
7. Pot furnace operation	0.2 kg/Mg[j] (0.4 lb/ton)	E		
8. Reverberatory furnace operation	4.15-4.35 kg/Mg of copper[c] (8.3-8.7 lb/ton of copper)	E		
9. Ductile iron innoculation	1.65-2.3 kg/Mg of iron[f,g,i] (3.3-4.5 lb/ton of iron)	D	Iron castings 13,490 (14,840)	26 (29)

Table 2-39 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR FOUNDRIES

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
10. Pouring molten metal into molds	0.05-2.07 kg/Mg in gray iron foundry[i,k,f] (0.1-4.13 lb/ton in gray iron foundry)	D	Iron castings 13,490 (14,840)	16 (17)
	1.26 kg/Mg for copper[l] (2.52 lb/ton for copper)	E		
	0.47 kg/Mg for lead[l] (0.93 lb/ton for lead)	E		
11. Casting shakeout	0.6-6.4 kg/Mg of iron[f,m] (1.2-12.8 lb/ton of iron)	E	Iron castings 13,490 (14,840)	47 (52)
12. Cooling and cleaning castings	cooling 0.08-0.4 kg/Mg iron castings[f,m] (0.16-0.8 lb/ton iron castings)	D	Iron castings 13,490 (14,840)	3 (4)
13. Finishing castings	0.005 kg/Mg iron castings[m] (0.01 lb/ton iron castings)	E	Iron castings 13,490 (14,840)	1 (1)
14. Core sand and core binder receiving and storage	Sand unloading 0.015 kg/Mg sand[n] (0.03 lb/ton sand)	E	Sand 2,600 (2,860)	1 (1)
15. Core sand and binder mixing	0.15 kg/Mg of sand[e] (0.3 lb/ton of sand)	E	Iron castings 13,490 (14,840)	30 (33)
	0.38-4.12 kg/Mg of iron[f,m] (0.75-8.24 lb/ton of iron)	E		
16. Core making	0.18 kg/Mg of cores[e] (0.35 lb/ton of cores)	E	Cores[o] 2,698 (2,968)	1 (1)

Table 2-39 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR FOUNDRIES

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
17. Core baking	0.015-2.7 kg/Mg of cores[m,p] (0.03-5.4 lb/ton of cores)	E	Cores[o] 2,698 (2,968)	4 (4)
18. Mold sand and binder receiving and storage	Sand unloading 0.015 kg/Mg sand[n] (0.03 lb/ton sand)	E	Sand 2,600 (2,860)	1 (1)
19. Sand preparation	0.67 kg/Mg iron castings[f] (1.3 lb/ton iron castings)	E	Iron castings 13,490 (14,840)	9 (10)
20. Mold makeup	0.02 kg/Mg iron castings[m] (0.04 lb/ton iron castings)	E	Iron castings 13,490 (14,840)	1 (1)

[a] Coke unloading emission factor based on the coal unloading emission factor presented in Section 2.1.2.

[b] For complete development of the storage emission factor refer to Section 2.1.4. For source 1b it was assumed that $S = 1.0$, $D = 90$, $K_1 = 0.85$, $K_2 = 0.40$, and $K_3 = 0.93$. Reference 5.

[c] Reference 4. (Approximately 5% of uncontrolled emissions.)

[d] Engineering judgment, assume 5% of uncontrolled emissions as reported in Reference 4, p. 7.8-1 and 7.9-2.

[e] Reference 6.

[f] Reference 7.

[g] Reference 8.

[h] Reference 9.

[i] Limited test data from Reference 10, indicate that emissions from electric induction furnace range from 0.15 to 0.3 kg/Mg (0.3 to 0.6 lb/ton) iron poured. These emissions include melting, pouring and innoculation.

[j] Engineering judgment, assume 50% of uncontrolled emissions as reported in Reference 4, p. 7.11-2.

[k] Reference 11.

[l] Reference 13.

[m] Reference 12.

[n] Sand unloading emission factor assumed to be of the same magnitude as the taconite pellets unloading emission factor as presented in Section 2.1.2. Emissions from storage is estimated to be negligible since the sand is normally stored indoors.

[o] Assume that 20% of the weight of castings equals the weight of cores.

[p] Engineering judgment, assume all uncontrolled emissions as reported in Reference 14, are fugitive.

Table 2-43. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR MATERIAL EXTRACTION AND BENEFICIATION

Source of IPFPE	Range of uncontrolled fugitive emission factors	Emission factor reliability rating	Emission factors by industry Kg/Mg (lb/ton)			
			Coal	Copper	Rock	P_2O_5 Rock
1. Overburden removal	0.0004[a]-0.225[b] Kg/Mq (0.0008-0.45 lb/ton) of ore	E	0.025[b] (0.45)	0.0004[a] (0.0008)		
	0.024[c]-0.05[d] Kg/Mq (0.048-0.10 lb/ton) of overburden	E	0.024[c] (0.048)			
2. Drilling and blasting	0.0005[e]-0.08[f] Kg/Mg (0.001-0.16 lb/ton)	E		0.0005[e] (0.0010)		
3. Ore loading	negligible[g]-0.05 Kg/Mg[h] (0.10 lb/ton) of ore	E-C[i]	(0.05)[h] (0.10)		0.025[i] (0.05)	NA
4. Haul road truck transport	0.23[j]-0.62[k] Kg per vehicle-kilometer traveled (0.8-2.2 lb per vehicle mile traveled)	depends on speed and controls				
5. Truck dumping	0.00017[l]-0.02[m] Kg/Mg (0.00034-0.04 lb/ton) of ore	E	0.01[n] (0.02)	0.01[n] (0.02)	0.02[m] (0.04)	NA
6. Primary crushing	negligible-0.25 Kg/Mg[o] (0.5 lb/ton) of ore	E	(0.01)[p] (0.02)		0.25[o] (0.5)	
7. Transfer and Conveying	negligible-0.75[g] Kg/Mg (1.5 lb/ton) of ore	E	0.10[r] (0.20)			0.75[q] (1.5)
8. Secondary crushing/ Screening	0.022[s]-0.75[t] Kg/Mg (0.044-1.5 lb/ton) of ore	E	0.08[u] (0.16)		0.75[t] (1.5)	
9. Waste disposal	negligible-3.23[v] Mg/1000m^2/yr (14.4 ton/acre/yr)	E				
10. Storage[aa]	0.0118[w]-0.2[x] Kg/Mg (0.0235-0.42 lb/ton)	E,D[y]	0.027[y]	0.165[x]	0.165[x]	0.10[z]
	0.392[x]-1.48[x] Kg/1000m^2/day (3.5-13.2 lb/acre/day)		(0.054)	(0.33)	(0.33) 1.1b Kg/1000m^2/day (10.4 lb/acre/day)	(0.20)
11. Land reclamation	use wind erosion equation	depends on climate and soil				

Table 2-43 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR MATERIAL EXTRACTION AND BENEFICIATION

[a] Reference 3. Estimate for open pit copper mining from comparison with emission rate for an active construction area.

[b] Reference 1. pp. 25. Estimate for lignite mining from comparison with emission rates from similar fugitive dust sources, such as construction and aggregate handling.

[c] Reference 6. pp. 25. Estimate for western surface coal mining from comparison of published emission factor[9] for aggregate handling and storage.

[d] Reference 7. Estimate of total fugitive emissions at western surface coal mine, with overburden removal the predominant contributor.

[e] Reference 3. Estimate based on visual observation at open pit copper mine.

[f] Reference 8. Estimate for granite drilling of 0.0004 Kg/Mq (0.0008 lb/ton) and 0.08 Kg/MG (0.16 lb/ton) for granite blasting.

[g] Reference 8. Estimate for crushed granite plant.

[h] Reference 1. pp. 35.

[i] Reference 9. From sampling of crushed rock loading by front-end loaders.

[j] Reference 10. Based on an uncontrolled "dry" rate of 1.04 Kg/VKT (3.7 lb/VMT) and application of a climate correction of 0.44 (the fraction of days when the surface was not wet or frozen) and a control factor of 0.50 to account for watering of the roads on dry days.

[k] Reference 1. Based on EPA's published emission factor for unpaved roads[11], 166 days per year with no rain or snow cover, and 50% control by watering during dry days.

[l] Reference 8. For dumping granite into a primary crusher.

[m] Reference 11. For dumping of crushed rock onto storage piles.

[n] Reference 1. Estimated by reducing the EPA published emission factor for unloading crushed rock to account for the larger size of the coal and ore being handled and its higher moisutre content.

[o] Reference 12. Includes both stack and fugitive emissions, 80% of which falls out on plant property.

[p] Reference 13.

[q] References 1 and 14. Based on reported industry estimates of 0.075 Kg/MG (0.15 lb/ton) with 90% control.

[r] Reference 15. Proportioned from a total fugitive emission factor of 0.22 Kg/Mg (0.44 lb/ton) for western surface coal mines.

[s] Reference 8. Includes both stack emissions and fugitive emission at a granite quarry.

[t] Reference 12. Includes stack and fugitive emissions, 60% of which falls out on plant property.

[u] Reference 13.

[v] Estimates for dried tailings based on U.S. Dept. of Agriculture's wind erosion equation (see Section 2.1) and are a function of regional climatic conditions, assuming no surface crusting.

[w] Reference 16. For coal mines in the Southwest based on the average wind erosion rate.

[x] Reference 17.

[y] Reference 14. Based on sampling tests on coal storage piles; does not include loading and unloading emissions.

[z] Reference 14.

[aa] For further detail refer to Section 2.1.4.

Table 2-46. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR COUNTRY AND TERMINAL ELEVATORS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
I. Terminal Elevators				
1. Receiving				
Truck unloading	0.16-1.75 kg/Mg unloaded^{a,b,c,d,e} (0.32-3.5 lb/ton)	D	Grain received 45,324 (49,980)	43 (48)
Railcar unloading	0.02-1.5 kg/Mg unloaded^{a,b,c,d,e} (0.04-3.0 lb/ton)	D	Grain received 67,986 (74,970)	52 (57)
Barge unloading	0.04-1.75 kg/Mg unloaded^{a,b,c,d,e} (0.08-3.5 lb/ton)	D	0 (0)	0 (0)
2. Transferring and conveying (total)	0.5-1.25 kg/Mg transferred^{a,b,d,e} (1.0-2.5 lb/ton)	D	Transferred and conveyed 113,310 (124,950)	99 (109)
2a. Receiving elevator leg and elevator head	0.25 kg/Mg transferred^{e,f} (0.5 lb/ton)	E		
2b. Garner and scale vents	f			
2c. Distributor, trippers, and spouting	0.25 kg/Mg transferred^{e} (0.5 lb/ton)	E		
2d. Storage bin vents	g			
2e. Turning	g			
3. Screening and cleaning	0.095-4.6 kg/Mg screened & cleaned^{a,b,d,e} (0.19-9.2 lb/ton)	D	Screened & cleaned 56,655 (62,475)	133 (147)
4. Drying	0.095-4.0 kg/Mg dried^{a,b,c,d,e} (0.19-8.0 lb/ton)	D	Dried 33,535 (36,975)	69 (76)

Table 2-46 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR COUNTRY AND TERMINAL ELEVATORS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
5. Shipping				
Truck loading	0.07-1.75 kg/Mg loaded[a,b,c,d] (0.14-3.5 lb/ton)	D	0 (0)	0 (0)
Railcar loading	0.007-1.5 kg/Mg loaded[a,b,c,d,e] (0.015-3.0 lb/ton)	D	Grain shipped by railcar 96,314 (106,208)	73 (80)
Barge or ship loading	0.001-1.75 kg/Mg loaded[a,b,c,d,e] (0.002-3.5 lb/ton)	D	Grain shipped by barge or ship 16,996 (18,742)	15 (16)
II. Country Elevators				
1. Receiving				
Truck unloading	0.16-4.0 kg/Mg unloaded[b,c,d] (0.32-8.0 lb/ton)	D	Grain received by truck 16,635 (18,322)	35 (38)
Railcar unloading	0.02-4.0 kg/Mg unloaded[b,c,d] (0.04-8.0 lb/ton)	D	0 (0)	0 (0)
Barge unloading	2.5-4.0 kg/Mg unloaded[b,d] (5.0-8.0 lb/ton)	E	0 (0)	0 (0)
2. Transferring and conveying (total) which includes following:	1.0-2.0 kg/Mg transferred[b,d,h,i] (2.0-4.0 lb/ton)	D	Transferred & conveyed 16,635 (18,332)	25 (28)
2a. Receiving elevator leg and head	j			
2b. Garner and scale vents	1.0 kg/Mg transferred[h,k] (2.0 lb/ton)	D		

Table 2-46 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR COUNTRY AND TERMINAL ELEVATORS

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
2c. Distributor, trippers and spouting	l			
2d. Storage bin vents	1.0 kg/Mg stored[h] (2.0 lb/ton)	E		
2e. Turning	m			m
3. Screening and cleaning	3.5-5.0 kg/Mg screened & cleaned[b,d,i] (7.0-10.0 lb/ton)	E	Screened & cleaned 4,159 (4,575)	20 (22)
4. Drying	0.095-4.0 kg/Mg dried[a,b,c,d,e] (0.19-8.0 lb/ton)	D	Dried 3,837 (4,232)	8 (9)
5. Shipping				
Truck loading	0.07-4.0 kg/Mg loaded[b,c,d,h] (0.14-8.0 lb/ton)	D	Grain shipped by truck 8,318 (9,161)	17 (19)
Railcar loading	0.007-4.0 kg/Mg loaded[b,c,d,h] (0.015-8.0 lb/ton)	D	Grain shipped by railcar 8,318 (9,161)	17 (18)
Barge loading	0.001-4.0 kg/Mg loaded[b,c,d,h] (0.002-8.0 lb/ton)	D	0 (0)	0 (0)

Table 2-46 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR COUNTRY AND TERMINAL ELEVATORS

[a] Reference 4.
[b] Reference 5.
[c] Reference 7.
[d] Reference 8.
[e] Reference 3.
[f] Emissions for garner and scale included in receiving elevator emissions.
[g] Emissions for storage bin vents and turning included in total.
[h] Reference 6.
[i] Reference 9.
[j] Emissions for receiving elevator (country elevator) included in total.
[k] This value is for scale vents only.
[l] Emissions for distributor, trippers, and spouting included in total.
[m] This operation is not normally done in country elevators.

Table 2-53. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR LIME PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Limestone/dolomite charging to primary crusher	0.00015-0.02 kg/Mg of rock charged[a] (0.00030-0.04 lb/ton)	D	Limestone/dolomite processed 100,000 (110,000)	1 (1)
2. Primary crushing	0.25 kg/Mg of limestone crushed[b] (0.5 lb/ton)	C	Limestone/dolomite processed 100,000 (110,000)	25 (28)
3. Transfer points and associated conveying	0.4 kg/Mg of quicklime produced[c] (0.8 lb/ton)	E	Quicklime produced 50,000 (55,000)	20 (22)
4. Primary screening	d			d
5. Secondary crushing	0.75 kg/Mg of limestone crushed[b] (1.5 lb/ton)	C	Limestone/dolomite processed 90,000 (99,000)	68 (74)
6. Secondary screening	e			e

Table 2-53 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR LIME PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
7. Crushed limestone storage				
Loading onto pile	$\frac{(0.02)\ (K_1)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[f] $\left(\frac{(0.04)\ (K_1)\ (S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Crushed limestone loaded 40,000 (44,000)	1 (1)
Vehicular traffic	$\frac{(0.065)\ (K_2)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material stored[f] $\left(\frac{(0.13)\ (K_2)\ (S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Crushed limestone stored 40,000 (44,000)	3 (3)
Loading out	$\frac{(0.025)\ (K_3)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[f] $\left(\frac{(0.055)\ (K_3)\ (S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Crushed limestone loaded out 40,000 (44,000)	1 (1)
Wind erosion	$\frac{(0.055)\ (S/1.5)}{(PE/100)^2}\ (\frac{D}{90})$ kg/Mg material stored[f] $\left(\frac{(0.11)\ S/1.5)}{(PE/100)^2}\ (\frac{D}{90})\ \text{lb/ton}\right)$	D	Crushed limestone stored 40,000 (44,000)	2 (2)
8. Quicklime screening	g			g

Table 2-53 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR LIME PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter Mg/yr. (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr. (tons/yr)
9. Quicklime and hydrated lime crushing and pulverizing with leaks from mill and from feed/discharge exhaust systems.	0.05 kg/Mg of quicklime and hydrated lime produced[h] (0.1 lb/ton)	E	Quicklime and hydrated lime crushed and pulverized 50,000 (55,000)	2 (3)
10. Lime product silo vents	i			i
11. Truck, rail, ship/barge loading of quicklime and hydrated lime	0.118 kg/Mg of lime products loaded[j] (0.236 lb/ton	E	Lime products loaded 50,000 (55,000)	6 (6)
12. Packaging quicklime and hydrated lime	Negligible - 0.005 kg/Mg of lime products packaged[k] (0.01 lb/ton)	E	Lime products packaged 10,000 (11,000)	Negligible

[a] Reference 1.

[b] Reference 2 - AP-42. 80% and 60% of which falls out on plant property for points 2 and 5, respectively.

[c] Engineering judgment, assumed approximately same as emission factor for dry phosphate rock as reported in Reference 3.

[d] Emission from primary screening (point 4) included in emission factor for primary crushing (point 2).

[e] Emissions from secondary screening (point 6) included in emission factor for secondary crushing (point 5).

[f] For complete development of this factor, refer to Section 2.1.4. For this example, it was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Reference 4.

[g] Emission from quicklime screening (point 8) included in emission factor for quicklime crushing and pulverizing (point 9).

[h] Engineering judgment based on controlled cement milling emissions reported by a cement manufacturing company.

[i] Emissions from lime product silo vents (point 10) included in emission factor for lime loading (point 11).

[j] Engineering judgment, assumed same as for loading of hydraulic cement obtained from Reference 5.

[k] Engineering judgment based on observations and emission tests of controlled similar sources.

Table 2-55. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR CONCRETE BATCHING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
1. Sand aggregate storage				
Loading onto pile	$\frac{(0.02)\ (K_1)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[b] $\left(\frac{(0.04)\ (K_1)\ (S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded onto pile)	D	Sand and aggregate loaded 20,000 (22,000)	negligible
Vehicular traffic	$\frac{(0.065)\ (K_2)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material stored[b] $\left(\frac{(0.13)\ (K_2)\ (S/1.5)}{(PE/100)^2}\right.$ lb/ton material stored)	D	Sand and aggregate stored 20,000 (22,000)	1 (1)
Loading out	$\frac{(0.025)\ (K_3)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[b] $\left(\frac{(0.05)\ (K_3)\ (S/1.5)}{(PE/100)^2}\right.$ lb/ton material loaded out)	D	Sand and aggreate loaded out 20,000 (22,000)	negligible
Wind erosion	$\frac{(0.055)\ (S/1.5)}{(PE/100)^2}\ (\frac{D}{90})$ kg/Mg material stored[b] $\left(\frac{(0.11)\ (S/1.5)}{(PE/100)^2}\ (\frac{D}{90})\right.$ lb ton material stored)	D	Sand and aggregate stored 20,000 (22,000)	1 (1)

Table 2-55 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR CONCRETE BATCHING

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory: Operating parameter, Mg/yr (tons/year)	Model plant fugitive emission inventory: Uncontrolled emissions Mg/yr (tons/yr)
2. Transfer of sand and aggregate to elevated bins	0.02 kg/Mg of sand and aggregate transferred[c] (0.04 lb/ton of sand and aggregate transferred)	E	Sand and aggregate transferred 60,000 (66,000)	1.2 (1.3)
3. Cement unloading to elevated storage silos	0.118 kg/Mg of cement unloaded[d] (0.236 lb/ton of cement unloaded)	D	Cement transferred to storage silo 7,000 (7,700)	0.8 (0.9)
4. Weigh hopper loading of cement, sand, and aggregate	0.01 kg/Mg of cement, sand and aggregate[c] (0.02 lb/ton of cement, sand and aggregate)	E	Cement, sand, and aggregate loaded 67,000 (73,700)	0.7 (0.8)
5. Mixer loading of cement, sand and aggregate (central mix plant)	0.02 kg/Mg of cement, sand and aggregate[c] (0.04 lb/ton of cement, sand and aggregate)	E	-	-
6. Loading of transit mix (wet-batching) truck	0.01 kg/Mg of cement, sand and aggregate[c] (0.02 lb/ton of cement, sand and aggregate)	E	Cement, sand, and aggregate loaded 67,000 (73,700)	0.7 (0.8)
7. Loading of dry-batch truck	0.02 kg/Mg of sand and aggregate[c] (0.04 lb/ton of sand and aggregate)	E	-	-

[a] AP-42 (Reference 2) reports total plant uncontrolled emission factor of 0.05 kg/Mg (0.1 lb/ton) of concrete produced.

[b] For complete development of this factor, refer to Section 2.1.4. For their example is was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Reference 3.

[c] Reference 4.

[d] Reference 5. From testing of mechanical unloading to hopper and subsequent transport of cement by enclosed bucket elevator to elevated bins with a fabric sock over the bin vent.

Table 2-57. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR ASPHALTIC CONCRETE PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
1. Storage of coarse and fine aggregate				
Loading onto pile	$\frac{(0.02)\ (K_1)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material loaded onto pile[a] $\left(\frac{(0.04)\ (K_1)\ (S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Aggregate loaded 277,100 (300,000)	5 (6)
Vehicular traffic	$\frac{(0.065)\ (K_2)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material stored[a] $\left(\frac{(0.13)\ (K_2)\ (S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Aggregate stored 272,100 (300,000)	18 (20)
Loading out	$\frac{(0.025)\ (K_3)\ (S/1.5)}{(PE/100)^2}$ kg/Mg material loaded out[a] $\left(\frac{(0.05)\ (K_3)\ (S/1.5)}{(PE/100)^2}\ \text{lb/ton}\right)$	D	Aggregate loaded out 272,100 (300,000)	7 (8)
Wind erosion	$\frac{(0.055)\ (S/1.5}{(PE/100)^2}\ (\frac{D}{90})$ kg/Mg material stored[a] $\left(\frac{(0.11)\ (S/1.5)}{(PE/100)^2}\ (\frac{D}{90})\ \text{lb/ton}\right)$	D	Aggregate stored 272,100 (300,000)	15 (16)

Table 2-57 (continued). IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR ASPHALTIC CONCRETE PRODUCTION

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
2. Unloading coarse and fine aggregate to storage bins	Negligible - 0.05 kg/Mg of aggregate[b] (0.10 lb/ton)	D	Aggregate processed 272,100 (300,000)	7 (8)
3. Cold aggregate elevator	Negligible - 0.1 kg/Mg of aggregate[b,c] (0.2 lb/ton)	D	Aggregate processed 272,100 (300,000)	14[e] (15)
4. Dried aggregate elevator	c		- .	c
5. Screening hot aggregate	Negligible - 0.013 kg/Mg of aggregate[d] (0.026 lb/ton)	D	Aggregate processed 272,100 (300,000)	2[e] (2)
6. Hot aggregate elevator (continuous mix plant)	c	-	-	c

[a] For complete development of this factor, refer to Section 2.1.4. For this example it was assumed that S = 1.5, D = 90, PE = 100, and K_1, K_2, and K_3 = 1. Reference 1.

[b] Reference 2.

[c] Emissions from points 4 and 6 are included in emissions from point 3.

[d] Reference 3.

[e] Emissions from these points for many plants are negligible, since these operations are generally enclosed and exhausted to the primary control system for the aggregate dryer (e.g., scrubber or fabric filter).

Table 2-59. IDENTIFICATION AND QUANTIFICATION OF POTENTIAL FUGITIVE PARTICULATE EMISSION POINTS FOR THE LUMBER AND FURNITURE INDUSTRY

Source of IPFPE	Uncontrolled fugitive emission factor	Emission factor reliability rating	Model plant fugitive emission inventory	
			Operating parameter, Mg/yr (tons/year)	Uncontrolled emissions Mg/yr (tons/yr)
Sawmill				
1. Log debarking	0.012 kg/Mg of logs debarked[a] (0.024 lb/ton of logs debarked)	E	Logs debarked 740,000 (820,000)	9 (10)
2. Sawing	0.18 kg/Mg of logs sawed[a] (0.35 lb/ton of logs sawed)	E	Logs sawed 650,000 (720,000)	117 (126)
3. Sawdust pile loading, unloading, and storage	0.5 kg/Mg sawdust handled[b] (1.0 lb/ton sawdust handled)	E	Sawdust handled 100,000 (110,000)	50 (55)
Furniture Manufacturing				
4. Wood waste storage bin vent	0.5 kg/Mg wood waste stored[b] (1.0 lb/ton wood waste stored)	E	Wood waste stored 1,360 (1,500)	1 (1)
5. Wood waste storage bin loadout	1.0 kg/Mg wood waste loaded out[b] (2.0 lb/ton wood waste loaded out)	E	Wood waste loaded out 1,360 (1,500)	1 (2)

[a] Estimate based on material balance of the waste produced by the specific operation and engineering judgement of the amount which becomes airborne.

[b] Engineering judgement based on observations on plant visits. It is recognized that in some plants this may be more of a severe problem.

AIR EMISSIONS IN IRON ORE MINING AND ENRICHMENT

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ABSTRACT

The iron ore industry has experienced radical change in the past 25 years and is growing rapidly today. There are a number of air emissions from this industry. The mining activity and the large areas of barren mines and dry tailings basins are the sources of fugitive emissions that are very difficult and costly to control. Based on the data available from tests at various sites, it is estimated that concentrating and pelletizing cause on the order of 100,000 tons of particulate emissions in the U.S. each year. Many of the sources contributing to these emissions already are controlled with devices that average nearly 99 percent efficiency. Some preliminary determinations of the characteristics of the particulate emissions are presented.

AIR EMISSIONS IN IRON ORE MINING AND ENRICHMENT*

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INTRODUCTION

The iron ore industry has experienced a radical change in the past 25 years. Although iron ore beneficiation has been going on for more than twice that long through the production of gravity concentrates, many natural ores were still shipped in the 1950's. Most of the higher grade ores have been mined and the vast reserves of lower grade ores (taconite) are now being used. These ores are concentrated (usually about 2.5 or 3 to 1) and shipped to the steel mills, mostly in the form of pellets. The importance of beneficiation can be illustrated by looking at Minnesota's 1973 shipments (more than 2/3 of U.S. production). That production consisted of 3 percent direct shipping ores, 27 percent gravity concentrates and 70 percent taconite concentrate pellets. Whereas the U.S. production of pellets in 1975 was approximately 60 million tons, it is expected to reach 90 million tons in 1978 as several major expansion projects come on line.

Midwest Research Institute is conducting "A Study of Emissions from Iron Ore Mining, Beneficiation, and Pelletizing" for the EPA's Industrial Environmental Research Laboratory. The emissions sources associated with beneficiation and pellet production are confined sources that lend themselves in standard control technology. Most of the emissions from mining and from tailings disposal are fugitive emissions and, as such, do not lend themselves to control other than through changing mining or handling procedures.

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The current program has not been completed; in fact, field testing is being completed the end of this month. Therefore, we are unable to report results of analyses of the sampling tests. Instead, this paper will give a description of the current U.S. iron ore industry as it relates to the air emissions. That description will include the mining, beneficiating and pelletizing processes; the emissions sources from those processes; the controls being used and something about the effectiveness of those controls. That will leave many unanswered questions in the minds of fugitive emissions experts. We hope to know more about these emissions when our current program has been completed. We will also discuss the constituents that could be expected to show up in the particulate emissions from this industry. Our current program should contribute to the overall knowledge in that area also. The rapid expansion of the industry will probably bring about technological changes in the way all emissions are controlled, so this industry will certainly remain of interest to those involved in the air pollution business for some time.

IRON MINING

Today's mining of iron ore is done almost entirely in open pit mines. After the overburden has been removed, the ore is removed along different levels, called benches. The operations that take place are drilling, blasting, loading and hauling.

Blastholes of 12 to 18 inches in diameter are drilled to a depth that is typically 35-50 feet deep, about 5 feet more than the bench height. The most common drills are jet piercing drills and rotary drills. The burners in the jet piercing drills are water cooled and the steam that is generated when the water contacts the hot taconite expands and flushes the spalled chips from the hole. The rotary drills use water flushing for dust suppression and cooling. Consequently, the drilling operations do not release many particulates.

The blastholes are loaded with explosives that are detonated to break loose up to nearly 2 million long tons of ore at one time. This process releases particulates, but it is not an important emission source. Most of the material thrown into the air is so large that it settles to the surface rapidly. Also, blasting is intermittent, occurring only once every several days, approximately once a week on the average. Meteorological conditions are monitored to find the best times for blasting with minimum noise and vibration. The pollutants from this source cannot be controlled, in the sense of entrapment.

The loading of ore is a process that contributes significantly to airborne pollutants. Large electric shovels (often 12 to 14 cubic yards) pick up the broken ore and dump it into trucks or rail cars. In most mines this is taking place at several sites, 24 hours per day. We feel that this is the largest source of airborne particulates resulting from ongoing mining activity. For that reason we are setting up a fugitive emissions sampling station at a shovel loading site as part of our current project; it will be a modified ambient sampling array such as that shown in Figure 1. Glass fiber filter media will be used to collect samples for mass loading measurements, for trace metals analysis (As, Cu and Ni), and for particulate sizing (Anderson). Membrane media will be used for collecting the samples for asbestos analysis. Although it would not be possible to control the dust that is raised as a result of filling the shovel, it is conceivable that the dust resulting from dumping the shovel load into a truck or train might be controlled.

Hauling the ore to the location of the primary crusher is a source of fugitive emissions, especially when trucks are used. When temperatures are above freezing, the mine roads are normally wetted down by water sprinkler trucks. This helps but does not eliminate the dust; the way roads are continuously being built and abandoned control of road dust would be extremely difficult. Finally, there is the dust that is raised on windy days from the barren surface of the mine (typically 1 to 10 square miles). This is another source that does not appear possible to eliminate or to control except through early revegetation of areas that have been mined out.

In summary, the amounts of particulate emissions in an open pit iron ore mine are not known and are generally difficult to reduce. We feel that a network of fugitive emissions sampling stations up- and down-wind from a mine would be beneficial in getting some preliminary data on the quantity and characteristics of pollutants that are carried outside of the mine.

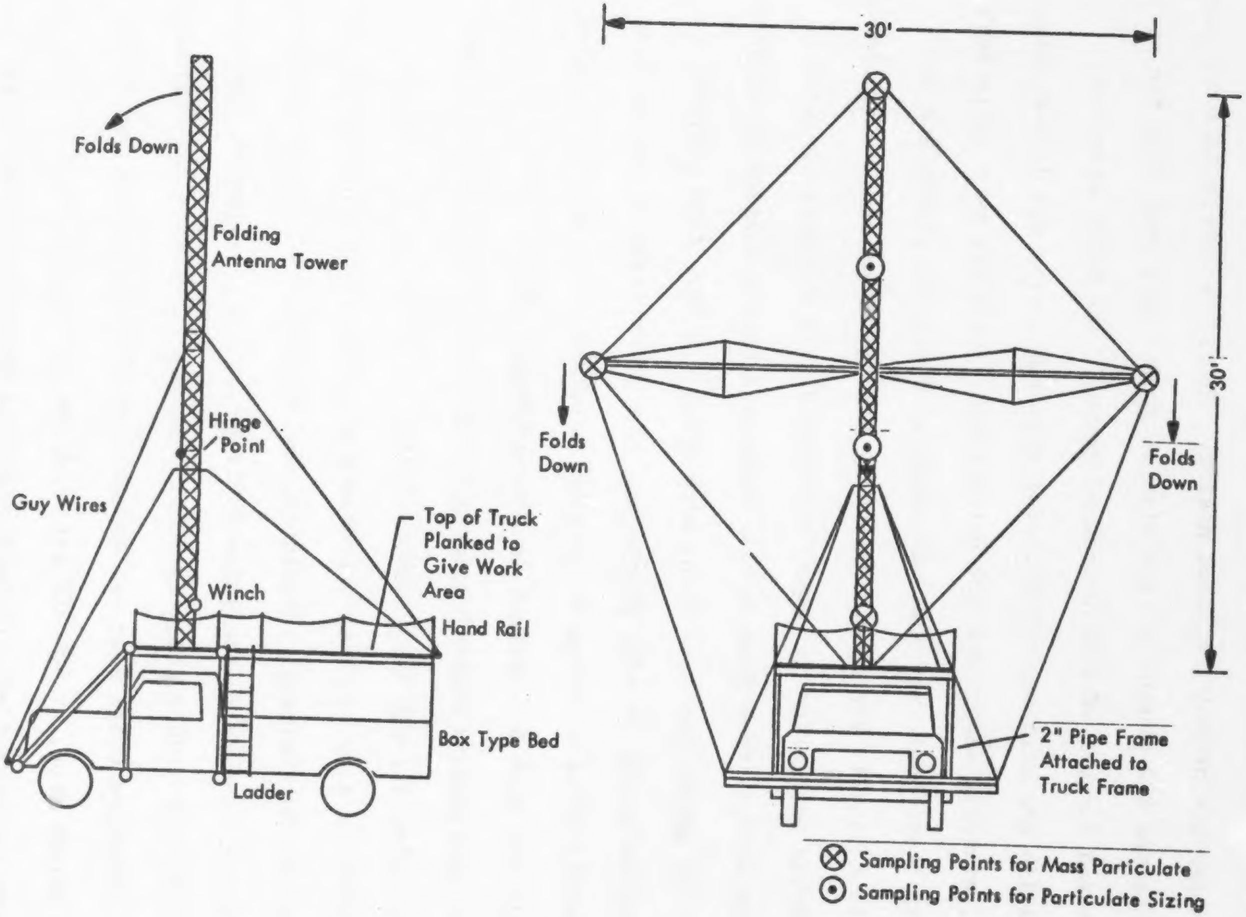
Folds Down
Folding Antenna Tower
Hinge Point
Guy Wires
Winch
Top of Truck Planked to Give Work Area
Hand Rail
Box Type Bed
Ladder
30'
30'
Folds Down
Folds Down
2" Pipe Frame Attached to Truck Frame
⊗ Sampling Points for Mass Particulate
⊙ Sampling Points for Particulate Sizing

Figure 1. Sampling Station for Fugitive Emissions

ORE BENEFICIATION

Approximately 40 percent of the iron ore that is mined in the U.S. becomes shippable product for iron making. Thus, the beneficiation process has to liberate 900 pounds of iron mineral grains from each long ton of crude ore and dispose of 1340 pounds of gangue. The basic steps to beneficiation are size separation, size reduction, size and density classification, minerals separation and dewatering. There are many variations in the way these basic steps are arranged in different plants but the process is basically the same. A typical beneficiation process flowsheet with magnetic separation is shown in Figure 2. In a relatively small percentage of U.S. ores iron is also separated by a flotation process.

The low grade iron ores being used today are very fine grained, so beneficiation begins by size reduction. The first stage is a reduction to approximately minus 6 inches in gyratory crushers. The size is further reduced to 1/4 inch to 3/4 inch in cone crushers. The crushing is generally dry with intermediate screening for size separation and recycle of the large particles through the crushers again.

Pollutants from crushing operations are controlled by a variety of scrubbers and by cyclones, rotoclones, and multiclones. Actual controlled emissions are usually in the range 0.012 to 0.12 gr/SCF (grans/Standard Cubic Foot), with 0.03 gr/SCF being typical. The gas flow rates are approximately 15 SCFM (Standard Cubic Feet per Minute) per LTPH (Long Tons Per Hour) process weight rate, or 900 SCF per long ton of crushed ore.

There are essentially no data available on baghouse control of crushing operations, and very few such systems exist. We are testing one of those operations as part of our current program. We will use sampling method EPA-5 (front one-half only) for collecting material for mass loading,

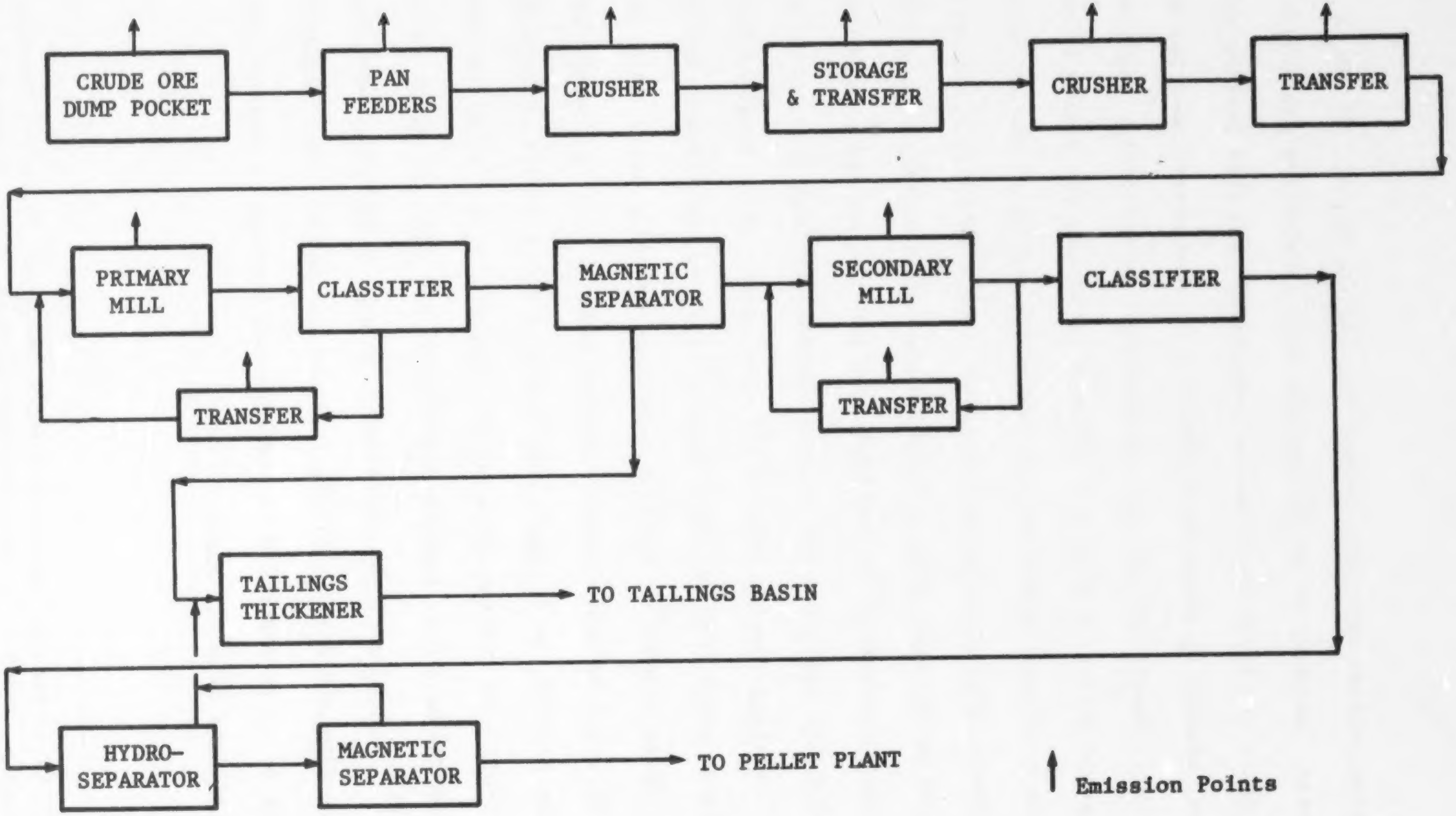
CRUDE ORE DUMP POCKET
PAN FEEDERS
CRUSHER
STORAGE & TRANSFER
CRUSHER
TRANSFER
PRIMARY MILL
CLASSIFIER
MAGNETIC SEPARATOR
SECONDARY MILL
CLASSIFIER
TRANSFER
TRANSFER
TAILINGS THICKENER
TO TAILINGS BASIN
HYDRO-SEPARATOR
MAGNETIC SEPARATOR
TO PELLET PLANT
Emission Points

Figure 2. Ore Beneficiation Flowchart

asbestos, silica and trace metals (As, Cd, Co, Cr, Mo, Ni, Pb, V, and Zn) analysis. Anderson or Brinks methods will be used for particle sizing.

After crushing, the fines are separated into iron bearing particles and gangue, usually by magnetic separators, and the coarse material moves on to grinding. Nearly all grinding is done wet, so nationally there is very little air pollution from that process. However, the sizing by screens and the ore handling and transfer while the ore is in the dry state contributes significantly to emissions. The same types of control devices are also in the same general range, being approximately 0.04 gr/SCF.

The outputs from the beneficiation process are the gangue that goes to a tailings basin and the mineral concentrate that goes to the pelletizing plant. Tailings basins (frequently many square miles in area) often have large areas that dry out, especially along the beaches, and these can become large sources of fugitive emissions on windy days. Much of the solid material in these basins has been reduced to a very small size in the grinding process, so it can become airborne quite easily. There is also truck traffic on unpaved roads at the disposal site. Fugitive emissions measurements have been conducted by MRI at one taconite plant tailings basin.(1) Modeling of the emissions from such a basin has been based on that sampling and a climatological dispersion model. That modeling gives a result of 25 tons per day as the expected fugitive emissions from a large tailings disposal basin.

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(1) Draft Environmental Impact Statement Technical Appendix; Reserve Mining Company's Proposed On Land Tailings Disposal Plan; Appendix E, Midwest Research Institute, "Air Quality" pp E177-E194; Prepared for State of Minnesota Department of Natural Resources and Pollution Control Agency, October 1975.

PELLETIZING

The pelletizing process consists of mixing the ore concentrate with a binder (bentonite), making green pellets in a balling drum, indurating the pellets, and cooling them. They are then stockpiled for shipping to the steel mills. A typical pelletizing flowsheet is shown in Figure 3.

The concentrate has been dewatered before entering the pelletizing plant, but is still wet enough to prevent dusting as it is handled and transported to where the bentonite is added. The powdered bentonite is added at a rate of 10 to 20 pounds per ton of concentrate. The bentonite can become airborne when it is loaded into bins, unloaded, blended with the concentrate, or transferred.

Bentonite emissions are usually controlled by scrubbers or bag filters, and contribute very little to the total emissions.

The ore concentrate with bentonite added is too wet to cause dusting as it moves to and through the balling drums and into the induration furnace or kiln. Most of the large plants and the new plants use grate-kiln systems. As the pellets tumble through the kiln, they begin to dust. There is a large volume of counter-flow gas moving through the kiln (main waste gas stream), and this becomes heavily loaded with particulates. Control of the waste gas streams at the different plants ranges from no control to the use of a wide variety of control devices. Typical emissions from controlled waste gas streams are 50 to 200 lb/hr and an uncontrolled stream will emit 4,000-5,000 lb/hr. A large percentage of the material from an uncontrolled source has a particle size so large that it settles to the surface very close to the plant; a somewhat smaller fraction of the emissions from the controlled waste gas streams settles out rapidly.

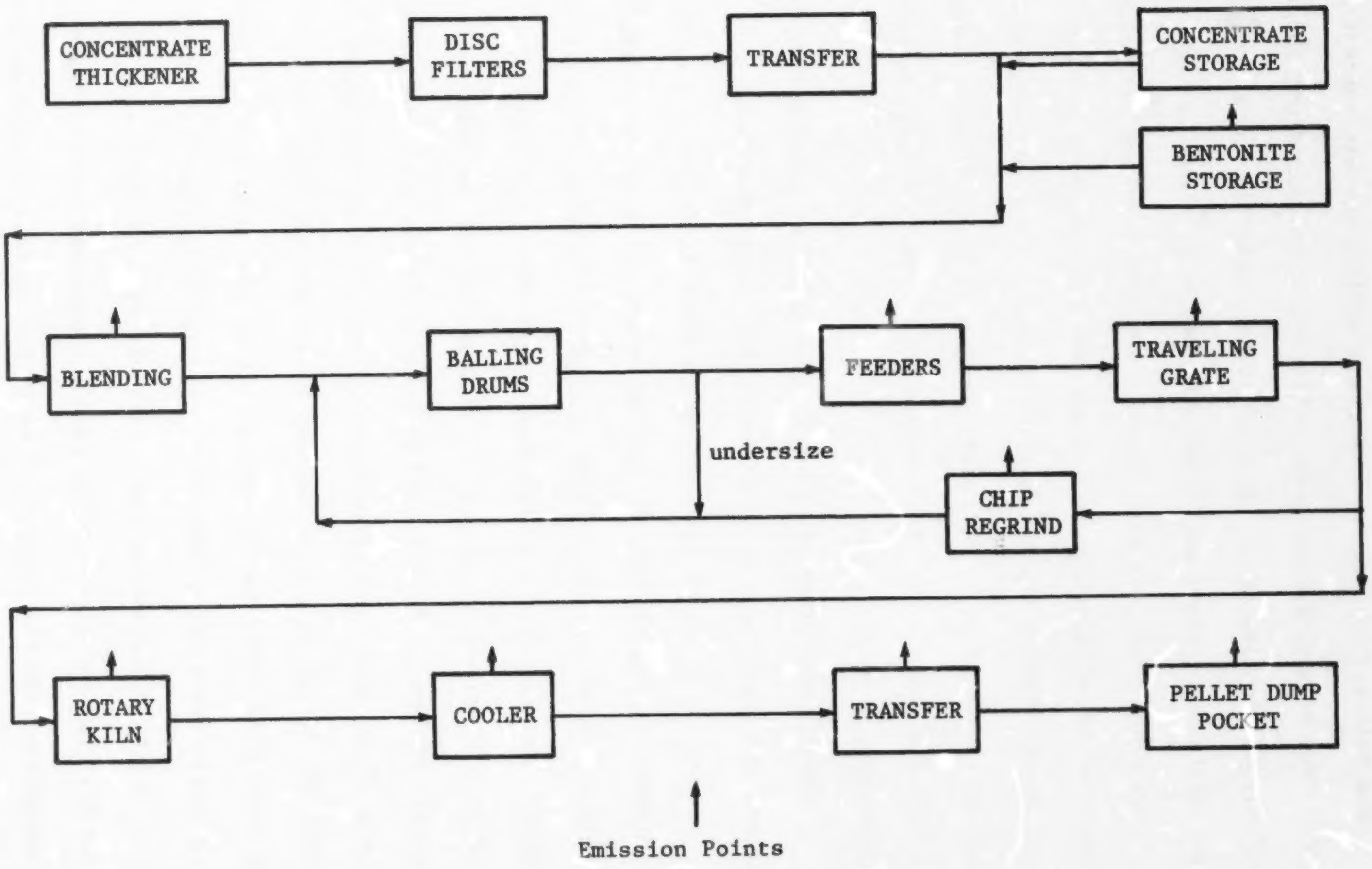
CONCENTRATE THICKENER
DISC FILTERS
TRANSFER
CONCENTRATE STORAGE
BENTONITE STORAGE
BLENDING
BALLING DRUMS
FEEDERS
TRAVELING GRATE
undersize
CHIP REGRIND
ROTARY KILN
COOLER
TRANSFER
PELLET DUMP POCKET
Emission Points

Figure 3. Pelletizer Flowchart

As the fired pellets emerge from a kiln they must be cooled before they are stockpiled. They commonly pass through an annular cooler with counter flow gas. There, the tumbling action abrades the pellets and causes some emissions. Most annular coolers do not have emission control devices and emit from 10 to 100 pounds per hour. The available information on annular cooler emissions is quite limited, so we are testing one as a part of our current program. Because many of the particles are being released by the autogenous grinding of the pellets as they move through the cooler, we expect that the average particle size might be quite small. If the particles are small they are quite significant, even if the tonnate is low, because they can remain airborne over greater distances.

Plants that use vertical shaft furnaces or straight furnaces rather than rotary kilns for induration could be expected to produce fewer emissions because there is not the tumbling action of a rotary kiln. That also applies for grate type cooling compared to the annular coolers.

Pellets emerging from the cooler are transported to the pellet loadout point. The emissions from loadout are usually controlled by equipment such as rotoclones and contribute very little to the overall emissions from a plant.

In addition to the emissions from the fixed sources, many plants have significant fugitive emissions within the buildings. Large fans are used for sweeping these to the outside or into a control device.

How much pollution does this add up to? In Table 1 we have shown the ranges of emissions for ten sources, estimated to be the ten most significant. The values are the low, median, and high value for all the plants for which data were available (typically 3 to 8 plants) and the units are in pounds per long ton of product. There are enough uncontrolled

Table 1. Ranges of Emissions (Pounds/Long Ton of Product)

Source	CONTROLLED			UNCONTROLLED		
	Low	Median	High	Low	Median	High
Dump Pocket	0.038	0.147	0.223	0.252	0.980	1.484
Crushers	0.004	0.013	0.063	0.143	0.227	0.627
Ore Transfer	0.0006	0.003	0.028	0.017	0.095	1.334
Fine Grinding/Milling	0.360	0.387	0.414	72	88	103
Bentonite Transfer	0.001	0.0004	0.001	0.011	0.044	0.128
Bentonite Blending	0.002	0.002	0.002	0.159	0.239	0.305
Grate Feed	0.007	0.009	0.015	0.035	0.697	1.47
Grate Discharge	0.002	0.011	0.015	0.088	1.46	1.53
Waste Gas	0.584	0.98	1.83	16.68	32.2	108
Pellet Handling	0.0004	0.018	0.037	0.021	3.75	5.23

sources and enough minor sources in the industry that we can assume the median value, controlled sources, to be a minimum figure. If we obtain the sum of median values and assume that value is applicable to U.S. production, we obtain an estimate of 57,000 tons per year. We also estimated the total U.S. emissions from pellet plants by adding the known emissions from four plants that account for 25 percent of U.S. production and multiplying the sum by four. These plants use technology that is typical of that used for most of the U.S. production. Using that method gives a sum of 112,000 tons of emissions per year. Most of the figures used for these calculations are from 1974 and there have been some additions of controls in old plants that would reduce those numbers. However, some new plant capacity has also been added so we feel it is safe to conclude that the emissions from the beneficiation and pelletizing of iron ore is of the order of 100,000 TPY.

It is also interesting to look at the difference between the median columns for controlled and for uncontrolled emissions in Table 1. The sum of the median values for uncontrolled sources is 80 times the sum for median level controlled sources. This shows that the controls that are now being used on those ten sources have a control efficiency of nearly 99 percent.

POLLUTANT CHARACTERISTICS

What are the pollutants from this industry? As stated earlier, the analyses of the samples from tests being conducted now have not been completed. However, there are some clues concerning what the pollutants might contain. In Table 2 is shown a typical chemical analysis of the tailings from a beneficiation plant, and in Table 3 is shown chemical analyses of five samples of igneous rocks from the iron range in Minnesota.

Arsenic compounds pose major problems in some foreign ores, but are rare in Minnesota ores. We could find only one indication that they do exist in Minnesota ores(2), and found no mention of arsenic with respect to other domestic ores. A sample of material was picked up from the floor of a baghouse hopper on a crushing operation outside of Minnesota and chemically analyzed. The results are shown in Table 4. Note an arsenic content of 5 parts per million in that sample. Because of the indication that arsenic compounds may be present, we are hoping to determine how much is in these ores.

In summary, iron ore mining, beneficiating and pelletizing is a massive industry that will soon mine approximately 350 million long tons of iron ore per year to produce 90 million long tons of pellets and nearly 40 million long tons of other concentrates. The extent to which this industry adds to air pollution outside the property lines of the mining companies and the characteristics of those pollutants is not well known. The present study being conducted for the EPA by MRI is a beginning. We are hopeful that it will lead to sound recommendations concerning the best opportunities for significantly reducing the emissions produced by iron ore mining, beneficiation, and pelletizing processes.

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(2) Private communication with Dr. Roland Blake, U.S. BuMines, who stated that Minnesota iron ores occasionally contain a few small crystallites of Arsenopyrite.

Table 2. Typical Chemical Analysis*

Element	Percent
Iron	14.93
Silicon	33.59
Aluminum	0.35
Calcium	1.67
Magnesium	1.96
Manganese	0.37
Titanium	0.030
Phosphorus	0.026
Sodium	0.040
Potassium	0.040
Sulfur	0.03
Lead	0.007
Zinc	0.004
Nickel	0.002
Copper	0.004
Chromium	0.004
Cadmium	0.0003
Molybdenum	<0.001
Vanadium	<0.001
Cobalt	0.002
Carbon	0.11
Hydrogen	0.10
Oxygen	46.64
Total	99.81

*Conference: Pollution of Lake Superior and Its Tributary Basin, Minnesota-Wisconsin-Michigan. Proceeding, Executive Session, Duluth, Minnesota, May 13,14,15, 1969, U.S. Department of the Interior, Federal Water Pollution Control Administration, Vol. 4, p. 1301.

Table 3. Chemical Analyses of Some Igneous Rocks of Minnesota*

Constituent	6	12	14	16	17
Fe_2O_3	(80.78)	35.14	46.14	46.92	22.50
FeO		32.40	21.53	27.87	35.68
SiO_2	2.02	13.81	21.65	5.69	8.86
Al_2O_3	2.68	4.00	4.89	7.23	5.51
CaO	trace	0.04	0.06	1.03	0.99
MgO	--	0.06	1.20	3.70	4.23
TiO_2	12.02	8.25	0	5.97	20.27
MnO	--	3.20	2.60	0.26	0.31
Cr_2O_3	2.40	2.05	1.01	0.03	0.19
V_2O_3	--	1.03	0.91	0.49	0.30
NiO	--	--	--	0.09	--
CoO	--	--	--	0.07	--
P_2O_5	0.03	trace	0.01	0.02	0.02
S	--	0	0	0.12	--
Na_2O	--	--	--	0.28	0.62
K_2O	--	--	--	0.24	0.20
H_2O	--	--	--	1.17	0.37
CO_2	--			0.26	--
Total	100.00	99.98	100.00	101.44	100.05

*A.P. Ruotsala and S.P. Tufford, "Chemical Analyses of Igneous Rocks", Minnesota Geological Survey, Information Circular 2, (1965)

**See following page for sample identifications

Sample Identifications for Table 3.

6. Magnetite ore.

Iron Lake, SE 1/4 sec 36, T. 65N., R. 3W., Cook Co.

[Minnesota Geological Survey Bulletin 6, p. 141 (1891)]

12. Magnetite ore (core at 75 ft depth)

Iron Lake, NE 1/4 NE 1/4 sec 1, T. 64N., R. 3W., Cook Co.

(Ibid., p. 106)

14. Magnetite ore (same core as No. 12, 65 ft depth)

Iron Lake, NE 1/4 NE 1/4 sec 1, T. 64N., R. 3W., Cook Co.

(Ibid, p. 106)

16. Magnetite band

Sec. 4, T. 63N., R. 12W., St. Louis Co.

[Minnesota Geological Survey Bulletin, 21, p. 74, (1926)]

17. Magnetite - Ilmenite

East of Benning Lake, sec 1, T. 64N., R. 2W., Cook Co.

Grout, The titaniferous magnetites of Minnesota,

IRRRC, St. Paul, p. 28 (1949-50)

Table 4. Sample Analysis From Taconite Ore in Crushing Operation

SAMPLE TYPES: Soil

SAMPLE(S) COLLECTED BY: Client

DATE RECEIVED: 01-07-77

BATCH NO: 40

	LAB NO:	54	54
	SAMPLE SITE:	TACONITE DUST	REPLICATE
ANALYSIS:		#1	#2
Arsenic, mg/kg as As		4	6
Cadmium, mg/kg as Cd		0.4	0.4
Cobalt, mg/kg as Co		20	20
Total Chromium, mg/kg as Cr		15	15
Copper, mg/kg as Cu		50	50
Molybdenum, mg/kg as Mo		40	40
Nickel, mg/kg as Ni		50	40
Lead, mg/kg as Pb		30	20
Vanadium, mg/kg as V		1000	1000
Zinc, mg/kg as Zn		23	23

ACKNOWLEDGEMENTS

The authors are indebted to Mr. Norman Plaks of EPA's Industrial Engineering Research Laboratory for his support and to Mr. Bruce Harris of the same laboratory for his assistance in selecting sources for sampling and analyses to be conducted.

DESIGN OF A STUDY TO MEASURE FUGITIVE EMISSIONS FROM PETROLEUM REFINING

By

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ABSTRACT

This paper describes the physical, chemical and statistical considerations involved in designing a study to sample and characterize fugitive emissions from petroleum refining activities. The factors affecting the choice of refineries and the individual samples are discussed in terms of their eventual contribution to the data base. The concept of choice and correlating variables is discussed and examples of its application are shown. The final factorial design with fractional replication is given.

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INTRODUCTION

Pollutants emitted into the air from a refinery fall into one of two categories:

- controlled emissions or
- fugitive emissions.

The first type is released into the air at a controlled rate from a point source such as a stack or a vent. The second is released without control of rate or direction. Many types of fugitive emissions cannot be measured by existing standard sampling and analytical techniques. Therefore, development of reliable measurement procedures is an essential prerequisite to the development of strategies for the control of fugitive emissions. This paper describes a program with dual objectives but will concentrate on the fugitive emission aspect and within that objective will concentrate on the design of the program.

The dual objectives are:

- to determine emission factors, i.e., total hydrocarbons and nonmethane hydrocarbons emitted from fugitive sources within typical refineries, and

- to assess the level and character of emissions in terms of hydrocarbon distribution and chemical functionality.

The decision to emphasize fugitive emissions in our current study is the result of discussions with the API and the EPA. The interest of the API stems from a need within the refining industry to have access to updated emission factors. The interest of EPA stems from its charge to develop adequate control technology for potentially hazardous pollutants and from a need for emission factors accurate and current enough to allow trade-off changes to be made in existing refining operations. The most cost-effective program should combine elements of both fugitive and nonfugitive source sampling.

Previous studies (1958) have dealt with total hydrocarbon emissions and with emissions of other criteria pollutants. This study will consider total and nonmethane hydrocarbons but will ignore other criteria pollutants except from nonfugitive sources where current data are not available. The present study will also seek to identify the individual compounds being emitted which may be potentially hazardous even at trace levels.

The makeup of a "refinery" is difficult to define since the process units employed are dependent on the demands for the refinery's products. Consideration is therefore given to a test plan that is not definition limited.

APPROACH

The type and arrangement of process units within refineries may vary considerably from one location to another; however, the individual unit fittings and processes contained in each refinery should show close similarities.

The unit fittings, ranging from valves, pumps, etc., to various seals, are available to industry in a smaller number of varieties than the varieties which may result from the various arrangements of the unit fittings to give unit processes. These fittings largely control the amount of fugitive emissions potentially available from a given unit process.

Thus, the approach is to experimentally determine the emissions from unit fittings. These data will allow calculation of the emission factors as well as calculation of the fugitive emission potential of individual unit processes.

In the case of operations involving fugitive emissions other than those from unit fittings, special sampling approaches have been devised to allow measurements or estimation of the total emissions from those operations.

SOURCES OF HYDROCARBON EMISSIONS

There are several known sources of hydrocarbon emissions in a refinery; they are listed in Table 1. Hydrocarbon emission sources other than stacks or vents were considered to be fugitive sources. Stacks or vents which can be identified as the principal hydrocarbon emission points were considered to be process sources. Some of the emission sources can qualify as either (or both).

Process emissions have received a great deal of study. Control technology development has been concentrated on the reduction of the emissions of hydrocarbons (and other criteria pollutants) from these sources.

TABLE 1. REFINERY HYDROCARBON EMISSION SOURCES

Process Emissions Sources:

- Compressor Engines
- Catalytic Cracker Regeneration Stacks
- Air Blowing
- Boilers and Process Heaters
- Flares and Blowdown Systems
- Vacuum Jets (Vented to the Atmosphere)
- Sulfur Recovery or Tailgas-Treating Unit Stacks

Fugitive Emissions Sources:

- Pipeline Valves
- Miscellaneous Joints
- Pressure-Relief Devices
- Pump and Compressor Seals
- Process Drains
- Blending Operations
- Cooling Towers
- Intermediate Storage Tanks*
- Blind Changing
- Maintenance Turnarounds (when vessels are vented to the atmosphere)
- Wastewater Systems
- Barometric Condensers on Vacuum Jets
- Loading Operations*
- Sampling
- Decoking Operations

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*Not within the scope of this work.

Fugitive emissions, however, have received only intermittant study since 1958. Fugitive emissions sources allow hydrocarbons to escape to the atmosphere principally by accident, inadequate maintenance, or poor planning. Some hydrocarbon leakage normally occurs even in the absence of such conditions. The sources are diverse both in their physical characteristics and in the means by which they allow hydrocarbon escape.

The next step is to define the procedures by which individual fugitive sources are to be selected for sampling. Criteria were selected for choosing the refineries to be visited and units to be sampled.

In evaluating all the possible variables which could affect fugitive emissions from refineries, it was useful to categorize these variables into choice parameters and correlating parameters. A choice parameter was defined as a variable that directly affects fugitive emissions in such a way that it should be set up as a category in planning the number of samples taken. Choice parameters are critical to selecting a statistically accurate sample.

All other factors which could affect the level of fugitive emissions will be used as correlating parameters. All pertinent information on each source sampled will be recorded during field testing. Attempts will then be made to correlate emissions to one, or a group of these parameters, yielding a more convenient method to apply the restraints of this study.

CHOICE OF REFINERIES AND PROCESS UNITS

The first step in designating specific sources for sampling was the choice of refineries. A rigorously accurate sampling procedure would include most, if not all, of the 256 refineries operating in the U. S. Such a large sampling plan would be virtually unmanageable as well as being cost-prohibitive. Therefore, a number of representative refineries were selected for sampling.

Refinery Location

Refinery location was an obvious variable. It has its principal effect upon the hazardous components generated within the refinery. It will influence the quality of the crude oil processed, and the nature and relative quantities of the products manufactured. The latter affects the severity of the operating conditions used in the process units as well as the types of units encountered. All of these considerations affect the by-products that result from processing the crude, and will influence the quantities and types of hazardous components produced.

However, it is not believed that location will have a direct effect upon rates of hydrocarbon emissions. Knowledge of the specific chemical species involved is not necessary for classification of overall leak rates from fugitive sources. Thus, this addresses the second of our objectives.

It was decided that location's effect on hazardous species would be investigated by sampling refineries in four different geographical regions. These are:

- East Coast,
- Gulf Coast,
- West Coast, and
- Middle U. S. (Midwest and Mid-Continent).

Refinery Age and Size

Two more principal parameters potentially useful in the selection of refineries for sampling are age and size. These variables affect such things as maintenance and degree of repair, quality of equipment, and equipment design. Their use as independent variables may not be entirely valid as closer examination shows.

There is no doubt that age affects the characteristics of refinery equipment and ultimately influences fugitive emissions.

There is some question, however, about the level at which age becomes a significant variable. Age has three levels of complexity:

- age of the entire refinery,
- ages of individual process units, and
- ages of individual pieces of equipment.

Age of the entire refinery is the most straightforward variable to use in the selection of refineries for sampling. New refineries have all new equipment and usually are more complex than older ones. Older equipment designs will be found in old refineries. Even when properly maintained, these could have greater emissions potential than newer models. If two refineries had identical maintenance budgets, more might be spent in the older one just to keep the equipment operational.

Use of refinery age can be inconclusive, however. Some of the equipment used in old refineries may be older, but many newer pieces of hardware, and even new units can be the result of turnarounds and expansions. Units having a variety of age will be located at the older refinery sites. Specific age groups and percentages of total capacity processed in old units are totally site-specific. Sampling an old refinery will not guarantee that all or any specific fraction of the equipment studies will be as old as the refinery site itself. It will, however, yield data taken from equipment having a mixture of ages which may tend to average somewhat the effect of age upon the emissions.

The next level of decreasing complexity is the process unit. Selecting process unit age as the criterion would eliminate the problem of expansions since entire units are usually constructed at one time. Turnarounds would remain a problem because any unit more than three years old has probably undergone at least one turnaround in which some of its hardware is replaced by newer equipment. This again causes an averaging effect, although newer units will have a smaller variety of age groups represented.

Equipment age is the most accurate variable to use in studying the effect of age upon hydrocarbon emissions. Specific operating lives of valves, pumps, etc., can be determined from refiners and/or manufacturers. Age categories can be defined for each equipment piece to be sampled, and the true effect of age determined.

There are several problems with this method. Primarily because determination of the ages of various equipment pieces will be difficult at best. Turnaround and maintenance records for each unit sampled would have to be checked to find the ages of various pieces of hardware. This would also be true for a refiner attempting to use the final results of the study.

Refinery size will have an effect on such things as the number and type of products manufactured, the number and type of hazardous species formed, the types of units available for sampling, the amount of effort put in on maintenance programs, and the quality of equipment purchased. The most obvious break in these factors is between very small and large refineries. In order to use size as some indication of complexity, it was decided that a realistic cut point is 50,000 bbl/day. A range of refinery sizes above and below this size should be sampled to prevent bias toward any individual size. Only those refineries having sizes within 10% of the cut point should be avoided.

Becuase of the definition of size, size and refinery or process age become dependent variables. There are not many new refineries significantly smaller than 50,000 bbl/day. Also, it would be difficult to find many new process units in refineries that small. Although the logical solution is to pick hardware age as the variable, implementation would be difficult if not impossible. Therefore, it is recommended that refinery age and size be broken into three categories:

- old/small,
- old/large, and
- new/large.

Large and small have been defined. Old will mean any refinery having its oldest operating unit more than 20 years old. New will mean having units no older than 10 years.

Maintenance Practices

It is very obvious that maintenance is the key to fugitive emissions and a precise characterization of refinery maintenance practices could be a valuable parameter in correlating fugitive emissions. Such a characterization, however, is very difficult.

An important distinction must be made between corrective and preventive maintenance. When a leak becomes bad enough to be detected by operating personnel, most refiners will assign maintenance forces to repair it without delay. It is this type of corrective maintenance that is reflected in cost factors, but it has very little bearing on total fugitive emissions. Over a period of time, the subject fitting will develop a small leak which degrades to the point where it is finally detected and fixed. The time delay between detection and correction represents only a small fraction of the time that the fitting has leaked. All those months of slow leaking are responsible for far greater total emissions. Only a preventive maintenance program wherein periodic checks are made of all valves, flanges, pumps, compressors, etc., can have a positive effect in decreasing fugitive emissions.

The real problem, then, is finding out which refiners practice preventive maintenance, and to what degree. This is perhaps best done by a survey of refiners as to whether or not any attempt at preventive maintenance is made, but it would still be difficult to evaluate the effectiveness of those employing such a program.

The conclusion of this analysis is that although maintenance is very significant in determining the magnitude of fugitive emissions, it is of no value as a choice parameter. The only way to determine the effectiveness of maintenance at a particular refinery would be to measure its fugitive emissions and compare this to the industry norm. This conclusion is supported by the fact that the Los Angeles County project (ST-427) noted significant differences in maintenance at the refineries they tested, and yet were unable to correlate their final results to show the effect of the maintenance factor. All significant parameters will be monitored during the field testing section in an attempt to quantify the maintenance factor, but no use can be made of it as a choice parameter. A survey method will be used on the refineries tested to check possible correlations.

Process Units to be Sampled

Temperature and pressure have major effects upon fugitive emissions from a refinery. They are available and useful variables and will be treated as choice parameters. In a refinery, there can be found as many combinations of temperature and pressure as one wishes to define. For the purposes of this sampling plan, four pressure/temperature classifications were employed:

- high pressure/high temperature,
- low pressure/high temperature,
- high pressure/low temperature, and
- low pressure/low temperature.

These terms are defined as follows:

- pressure -
    - high - >150 psig,
    - low - <150 psig, and

- temperature -
    - high - >100°C, and
    - low - <100°C.

Several process units fall within each category of pressure/temperature. It is doubtful that a single unit will have each size, type and service that will be defined for each piece of hardware. In most cases, several units will have to be sampled to completely fill the required variable categories. In the event that all of the desired equipment categories do exist on one process unit, samples will still be taken from as many other units as possible. This will serve two purposes. Bias toward a particular unit will be eliminated, generating data more representative of the pressure/temperature class as a whole. Also, differences between various units can be noted when the data are analyzed. There may not be enough data to draw firm conclusions about characteristic process emissions, but it will give indications of the factors that may be significant.

It should be noted that the four pressure/temperature classifications are simply guidelines by which units most likely to have hardware in service at the desired conditions can be identified for sampling. High pressure and temperature units also employ valves, fittings, etc. that fall into the lower pressure and temperature ranges. These need not be ignored, but can be sampled, also, to fill appropriate choice variable categories.

Summary

Refineries will be chosen for sampling based on three criteria:

- location,
- age, and
- size.

Within each geographic location refineries from three age/size categories will be chosen. One refinery will be sampled from the classifications old/small and new/large. Two old/large refineries in each geographic location should be sampled. This will allow a greater chance for older equipment to be included in the sampling scheme (since not all of the equipment in old refineries is old). This sets the total number of refineries to be sampled at 16.

BAGGABLE SOURCE VARIABLES

Variables affecting the fugitive emissions from baggable sources can be classified into choice and correlating parameters, as were the refinery selection variables in the preceding section. The variables can then be further defined according to availability and usefulness. Availability is determined based on the expected level of difficulty encountered in obtaining the necessary data in the field. Some information, such as pressure or temperature, is readily available. Other facts, such as length of time since a seal was replaced, would be very difficult to ascertain by the sampling team. The final usefulness of the variable in the computation of the fugitive emissions from a refinery was also considered. Some very important variables were not categorized for sampling because of their lack of ultimate usefulness. For example, using actual length of service for each equipment piece would not yield useful information because it is doubtful that refiners know how long each pump seal, valve, flange gasket, etc. has been in service.

Prioritizing variables according to these criteria allowed the most significant ones to be determined for each baggable source. Decisions were then made concerning which categories should be used to define the types and numbers of fugitive sources to be sampled.

STATISTICAL APPROACH

The Value of a Statistical Approach

Seven variables have been selected as potentially important for describing the leakage of baggable devices in refineries. The variables include device type and size, temperature and pressure of operation, gas or liquid service, and refinery location, size and age. Even after dividing the range of each variable into a minimal number of subcategories, about 8,000 samples would be required to measure the leakage from each combination of the variables just once. Obtaining a statistically significant sampling for each combination of the variables would require several times as many measurements.

Fortunately, sampling plans utilizing fewer measurements can be used to determine leakage rates within the desired accuracies. By assuming that complicated interactions between the variables are unimportant, the number of necessary measurements is reduced considerably. Factorial experiment design procedures can be used to select test combinations of the variables so that the effect of each variable on the leakage rate can be determined. Analysis of variance can be used to determine which variables significantly affect the leakage rate. In our case, both the magnitude of leakage rates and confidence intervals for the estimates will be calculated. When appropriate, regression analysis will be used to estimate trends. Tests of the validity of the assumption that higher order interactions are negligible will indicate areas where more measurements are required.

The value of statistical experimental design is that it provides a systematic and orderly procedure for selecting a specific set of measurements for a sampling program. The design is based on assumption about the probability distributions of errors, independence of effects of different variables, and the insignificance of multivariable interactions. As the data begin to come in, the validity of our assumptions will be tested and adjustments made to the sampling plan.

Structured flexibility forms the tone of the sampling plan. The structure assures that all preconcerned measurement and analysis requirements are efficiently covered. Flexibility will be maintained within a procedural framework to apply what is learned toward subsequent sampling and analysis.

The sampling plan structure consisted of outlining detailed procedures before sampling begins. This included:

- specifying "choice" and "correlation" variables (choice variables specify sampling categories, while correlation variables are others we wish to record because they might be important);
- developing a form for recording sampling and analysis results, and
- defining data analysis procedures and outputs -
  - data digitizing,
  - graphic and tabular presentation of raw data,
  - analysis of variance to select important variables,
  - predicted leakage rates, with confidence intervals,
  - tests for validity of assumption, and
  - correlations of effect of variable pairs.

The flexibility to respond to preliminary results includes altering choice variable categories for several reasons. Inconsequential leakers may be dropped, new categories may be added (based on preliminary results or engineering judgment) and the most important "correlation" variables may be converted to "choice" variables. Also, the data analysis procedures may be improved as the sampling proceeds.

Factorial Experiment Design

Standard statistical techniques have been developed for handling large numbers of variables, or "factors". The methods are especially useful when only a few values of each variable need be considered. Some important properties of the factorial design for this program are described below.

- First, a list of the variables (factors) which were expected to most strongly influence the dependent variable was prepared. In this case, the dependent variable was the leakage rate for each type of equipment.

- A number of levels, or ranges of values, were selected for each factor. The decision was based on a trade-off between precision of results (many levels) and economy (few levels per variable). The preliminary selections for independent variables and their numbers of levels were:

Choice of Refinery

(1) 4 geographic locations

(2) 3 age/size categories:
- new/big
- old/little
- old/big

Operating Conditions

(3) 4 temperature/pressure combinations

(4) 2 types of service (gas/liquid)

(5) 3 sizes

Device Types

(6) 8 device types:
- block in-line valves
- control in-line valves
- open-end valves
- flanges
- pressure-relief devices
- pump seals
- compressor seals
- unit drains

- Each sample was identified by a set of levels, one for each factor. For example, a measurement could be obtained for the third location, largest size, old category, second temperature/pressure category, etc.

- Factorial experiment design is a systematic procedure for selecting a balanced set of experiments. All levels for each variable are tested an equal number of times, with evenly distributed values for the other variables. The result is maximum efficiency, the same data set is equally suitable for determining the effect of all factors.

- Complete replication refers to a sampling plan in which measurements are performed for all possible combinations of variables. For the preliminary variable selections, about 8000 samples are required for each complete replication.

- Fractional replication refers to balanced subsets of the complete design which can be analyzed for the effect of each variable. The ability to analyze for higher order interactions between the variables is lost.

  Fractional replications are used to obtain an overview of the results after a limited number of samples have been obtained. An estimate of the effect of each factor on the leakage rate is available. The accuracy of the estimates may still be low because of the small number of samples.

- A sampling plan which adapts according to the early results will be the most efficient. The proposed procedure covers all possibilities by first performing a fractional replication and analyzing for the effects of all factors on the leakage rate. At this point, some types of devices or variables will be found to be adequately characterized. This could be because their contribution to total emitted hydrocarbons has been found to be small, or possibly because some factor has a small effect on the amount of emissions.

The subsequent sampling plan will be designed to focus on those remaining factors which are most important for understanding the total hydrocarbon emissions situation for a "typical" process unit. The order of experiments will be selected so that fractional replications of variable sets will be completed at regular intervals. The results will be analyzed at these times. The sampling plan will be adapted at these decision points, so that the project goal of identifying the emission properties of equipment types and typical process units is most efficiently and thoroughly accomplished.

Number of Required Samples

The experimental design procedure which most efficiently utilizes the data is adaptive in nature. Therefore, the number of samples necessary to achieve a given hydrocarbon emissions accuracy cannot be precisely determined. The procedures for selecting samples and analyzing the results will now be described.

The initial choice variables for baggable sources can be divided into refinery variables and device-type variables. The refinery variables are:

- 4 geographical locations,
- 3 age/size categories,
    - new/big,
    - old/little, and
    - old/big.

Twice as many old/big refineries will be sampled relative to the other two age/size categories. This is because old and large refineries are common and they should contain a broad spectrum of device types, ages, and maintenance conditions.

The device-type variables for baggable sources are:

- 48 in-line valve categories:
    - . 2 gas/liquid,
    - . 2 block/control,
    - . 3 sizes,
    - . 4 temperature/pressure conditions,
- 2 open-end valve categories:
    - . sampling/drain,
- 16 flange categories:
    - . 2 gas/liquid,
    - . 2 sizes,
    - . 4 temperature/pressure,
- 6 pressure-relief device categories:
    - . 2 gas/liquid,
    - . 3 temperature/pressure (low temperature/low pressure excluded),
- 99 pump-seal categories:
    - . 3 sizes,
    - . 4 temperature/pressure,
    - . 3 shaft and packing classes,
    - . 3 Reid vapor-pressure classes (for 3 temperature/pressure classes),
    - . 2 Reid vapor-pressure classes (for the other temperature/pressure class),

- 2 unit drain types, and

- compressor seals (all compressors will be sampled).

For logistics reasons, it will be desirable to complete the measurements at each refinery before moving to the next site. A possible sampling plan for the first refinery is listed below:

Device Type	No. of Replications	Samples Per Replication	Total Samples
In-Line Valves	4	48	192
Open-End Valves	4	2	8
Flanges	2	16	32
Pressure-Relief Devices	8	6	48
Pump Seals	1*	189	189
Unit Drains	4	2	8
Compressor Seals	1	(all)	(all)
Total Samples =		477 + (all compressors)	

*The replications for pump seals have been selected according to the RVP category of the fluid being pumped. Thus:

1 replicate - RVP<1.5
2 replicates - 1.5<RVP<26
3 replicates - RVP>26

The number of replications per device type is selected according to expected leakage rates and measurement accuracies.

For subsequent refineries, approximately the same number of measurements will be obtained. The distribution of samples among the device types at each stage will depend on what has been learned about:

- leakage rate for each device type,
- precision and accuracy of measurements,
- prevalence of device types in refineries, (this relates leakage to total emissions), and
- relative toxicity of leakages.

The total number of baggable source samples obtained will be about 8000 (500 each for 16 refineries).

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SOME AIR QUALITY AND ENERGY CONSERVATION CONSIDERATIONS FOR THE USE OF EMULSIONS TO REPLACE ASPHALT CUTBACKS IN CERTAIN PAVING OPERATIONS

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ABSTRACT

This paper reviews practices found in the use of liquified asphalts for paving purposes. It examines (1) the solvent content difference in asphalts liquified with petroleum distillates (cutback asphalts) and asphalts liquified using water and an emulsion, and (2) the amounts of hydrocarbons emitted when using cutback asphalts in relation to national and state hydrocarbon emissions. The substitutability of cutbacks and emulsions are discussed. Energy conservation considerations are treated. The results of an eight-state telephone survey of highway paving practices are presented.

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Executive Summary

This paper examines the air quality and energy conservation aspects of asphalt paving practices using liquified asphalt. There are two basic types of liquified asphalt: (1) asphalts liquified with petroleum distillates such as kerosene or heavy naphtha, called cutback asphalts, and (2) asphalts liquified using water and an emulsifying agent, called emulsified asphalts. Both types of liquified asphalt are "cured" through the evaporation of the liquifying constituent. Cutbacks emit reactive hydrocarbons during the curing process; emulsions emit almost no air pollutants.

In 1975 cutbacks accounted for 2.3% of estimated national hydrocarbon emissions. In some states the cutbacks accounted for more than 15% of the state's estimated total hydrocarbon emissions. Some states, e.g., Wisconsin, Indiana, Illinois, Ohio, Pennsylvania, Virginia, and West Virginia, have significant air stagnation problems and require regulatory control of hydrocarbon emissions to attain and maintain oxidant air quality standards. These states also have had significant hydrocarbon emissions attributable to paving with cutbacks. Since asphalt paving operations occur predominantly during warm-weather months, when formation of oxidants from photochemical synthesis of hydrocarbon emissions is most prevalent, the decreased use of cutback asphalt could provide major assistance in oxidant attainment and maintenance strategies.

It is estimated that in 1975 more than 10 million barrels of petroleum distillates were used nationally to liquify asphalt for paving purposes. These distillates represent fuels which were evaporated to the atmosphere

or were retained in the pavement. The total energy associated with laying one gallon of cutback asphalt as pavement is about 50,200 Btu, while the total energy associated with a gallon of emulsified asphalt is about 2,830 Btu. For these reasons, the use of emulsified asphalt as a replacement for asphalt cutback has energy benefits.

There are only three known instances when emulsions cannot be substituted for cutbacks: (a) when long-life stockpiles are required, (b) when ambient temperatures fall below about 50°F, and (c) possibly when used as a penetrating prime coat. The price difference between the two types of liquified asphalt was found to be not significant at this time.

Although there have been continuing and extensive efforts through paving operation channels (highway engineering offices and the asphalt paving industry) to promote the use of emulsions, no similar efforts have been made to inform the general public and environmental groups of the energy and environmental benefits accruing from the increased use of emulsified asphalt.

I. Purpose of Study

The purpose of this paper is to examine potential reductions in hydrocarbon emissions which may be achieved through substituting one kind of liquified asphalt for another in certain paving operations. The paper reviews (1) the differences in asphalts liquified with petroleum distillates (cutback asphalts), and (2) asphalts liquified using water and an emulsifying agent (emulsified asphalts). Amounts of reactive hydrocarbons emitted when using cutback asphalts are discussed, as well as the substitutability of emulsified asphalts in place of cutback asphalts. Energy conservation considerations are presented, and the results of an eight-state telephone survey of highway paving practices are summarized.

II. Asphalt Paving - General

Asphalt is a by-product of petroleum distillation (natural or man-made) which man has put to use in many different ways. In ancient times he used it in its natural form to caulk boats and ships, as mortar in masonry construction, and as a cement for mending stone tools. Now we use it for roofing, weatherproofing, floor tile, insulating materials, molded electrical equipment, papers, shingles, coatings, and many other applications. One of its better known uses is for pavements. Because of its durability and weather resistant qualities we use it in many different paving applications. These pavement uses can range from a thin layer sprayed on a dirt road to keep down dust, to a heavy duty pavement of thick layers of asphalt mixed with aggregate (crushed rock, gravel, slag or sand) placed on a well prepared base and designed to carry heavy traffic. In between these two extremes, asphalt pavement may be of a wide variety of thicknesses and strengths, depending on the traffic it will have to carry.(1)

Asphalt surfaces and pavements are composed of compacted aggregate and asphalt. Aggregate materials are produced from rock quarries as manufactured stone or obtained from natural gravel or soil deposits. Metal ore refining processes produce artificial aggregates as a by-product. The aggregate performs three functions. It transmits the load from the surface to the base course, takes the abrasive wear of traffic, and provides a nonskid surface. The asphalt binder holds the aggregate together, preventing displacement and loss of aggregate, and provides a waterproof cover for the base. Asphalts take the form of asphalt cement (the residue of the distillation of crude oils), and liquified asphalts, called asphalt cutbacks (asphalt cement thinned, or "cut back" with volatile petroleum distillates such as naphtha, kerosene etc.), and asphalt emulsions (nonflammable liquid, produced by combining asphalt and water with an emulsifying agent such as soap). Asphalt cement, which is semi-solid, must be heated to convert it to a usable liquid. A slight amount of heat is often used with cutbacks to facilitate spraying. Asphalt emulsions normally do not require heating. Asphalt cutbacks and asphalt emulsions are produced in a wide variety of types and grades related to intended use, curing time and structural design requirements. Some of the uses are defined in Appendix A.

Emulsified asphalts are used widely in the construction and maintenance of pavements ranging from high-traffic-volume highways and airports to low-volume rural roads and city streets. Although emulsions have been available since 1903 and used extensively since the 1930s, recent energy and environmental problems have focused attention on increased use of these materials. The use of emulsions can reduce energy requirements by reducing or eliminating petroleum distillates that are used in liquified asphalts and by lowering heating requirements, especially in heating aggregates to dry them. The elimination of petroleum distillates also reduces air pollution by eliminating emissions of hydrocarbons evaporated during the curing process.

Asphalt paving is a seasonal operation, with cold temperatures and rainy weather severely limiting construction and maintenance operations. Winter-time paving is limited to emergency repairs, usually of pot-holes. Emulsified asphalts usually are not used when rain is anticipated or when temperatures fall below 50°F. Generally speaking, emulsified asphalt can substitute for cutbacks in almost any application. Some believe that emulsions are not good for priming purposes, others believe that proper soil preparation is the answer, and still others question the very need for priming. Emulsified asphalt is not recommended for long-term stockpiling (more than 3-4 weeks). The same construction equipment used for cutbacks can be used for emulsions. A moderate amount of training (one or two days) is recommended before first using emulsions. This training is readily available from members of the Asphalt Emulsion Manufacturers Association. Local policies which encourage the use of cutbacks are the only known institutional constraints that inhibit the use of emulsified asphalt. Appendix B presents more detail on the advantages and limitations of emulsified asphalts.

III. Previous Efforts to Encourage Emulsified Asphalt Use

Some of the organizations concerned with energy problems affecting the supply and use of asphalt road paving materials are: Department of Transportation (DOT), Federal Highway Administration (FHWA), Federal Energy Administration (FEA), U. S. Department of Agriculture (USDA), Forest Service, Environmental Protection Agency (EPA), Transportation Research Board (TRB), National Asphalt Pavement Association (NAPA), The Asphalt Institute (AI), Asphalt Emulsion Manufacturers Association (AEMA), American Society for Testing and Materials (ASTM), American Road Builders Association (ARBA), American Association of State Highway and Transportation Officials (AASHTO), and state and local highway agencies.

In December 1973 and again in January 1974, FHWA issued notices concerning fuel conservation in federally funded highway construction programs.(2) These notices encouraged state officials to minimize the use of cutback asphalts by substituting emulsions and to reduce mixing temperatures. They also provided guidelines on conserving fuel and presented analyses which demonstrated the large quantity of petroleum distillates which could be saved by substituting emulsified asphalts for cutbacks. FEA and EPA studies resulted in the conclusion that increasing fuel prices had already established a trend of increased use of emulsions. To accelerate this trend, FEA contracted with the National Research Council's Transportation Research Board to produce a synthesis report(2) on the use of asphalt emulsions for pavements. This report was widely publicized by DOT and various trade associations. FEA alone distributed 4,700 copies to city and county engineers in December 1975. In October 1975, EPA informed its regional offices by letter of the advantages of emulsified asphalts over cutbacks and advised the regional offices to encourage the use of emulsions to save energy and reduce emissions of hydrocarbons.

Other agencies and organizations have been at work on the problem. For example, NAPA and AI have published papers on energy conservation in highway paving, AEMA has been making extensive efforts throughout its membership to encourage the use of asphalt emulsions, and USDA Forest Service has published a report on its experience in using asphalt emulsions, as has the Navajo Area Bureau of Indian Affairs.(10)

IV. Air Quality Considerations

The volatiles in cutback asphalts release hydrobarbons into the atmosphere in amounts that vary according to the type of cutback.

Cutback asphalts fall into three broad categories: Slow Cure (SC) (sometimes referred to as Road Oil), Medium Cure (MC) and Rapid Cure (RC). Cutback content averages 35% diluents.(4) SCs are a fairly heavy crude oil in the Bunker C range. MCs are diluted with a kerosene-type solvent. RCs are diluted with a heavy naphtha or a gasoline-type solvent.

Table 1 is a summary of estimated hydrocarbon emissions resulting from the use of cutback asphalts for paving purposes. The emission calculations are based on the 35% volatiles contained in the cutbacks(3) and on the following evaporation amounts estimated by The Asphalt Institute(6): SC - 20%-30% evaporated (average: 25%), MC - 50%-60% evaporated (average: 55%), and RC - 70% evaporated. Although no known measurements of evaporation rates have been made, it is believed that most of the loss takes place early during paving operations. Continuing amounts are lost to the atmosphere as time goes by but at an ever decreasing rate, according to the Asphalt Institute(6).

Table 1

Summary of National Hydrocarbon Emission Estimates from the Use of Cutback Asphalt Paving Products

	All Volatiles (Incl HC) (Total tons/year)	HC Emissions (tons/year)
1971	1,916,857	964,476
1972	1,830,724	933,920
1973	1,975,451	1,014,524
1974	1,613,454	817,753
1975	1,434,895	742,203

It is important to remember that paving operations are seasonal and that the paving season occurs during the warm weather months when formation of oxidants from photochemical synthesis of hydrocarbon emissions is most prevalent. Attempting to arrive at specific answers to questions about photochemical reactivity of the hydrocarbons emitted by cutbacks is complicated by the fact that there are so many cutbacks of varying chemical compositions. The situation is further complicated by the variables of solar radiation, cloud cover, air mass stagnation, hydrocarbon concentrations, and oxidant formation. However, cutbacks can be classified as moderately to highly reactive as far as oxidant formation is concerned.(5,6)

Emulsified asphalts, on the other hand, consist of asphalt liquified with water containing an emulsifier. Emulsions are relatively pollution-free with few volatiles to evaporate into the atmosphere.(7) FHWA has pointed out that there may be some distillates in some formulations of emulsified asphalt.

Table 2 indicates the relationship of hydrocarbon emissions from cutback asphalts used in paving, to national hydrocarbon emissions. (Asphalt paving operations are not included as a source of HC emissions in the national summary). Although the figures in Table 2 are estimated, the conclusion of Table 2 is that cutback asphalt accounts for over 2% of national hydrocarbon emissions.

Table 2

Hydrocarbon Emissions from Cutback Asphalt as a Percentage of National HC Emissions

	Summary of National HC Emissions (10^6 tons/year)	Relationship of Cutback Asphalt HC Emissions to National HC Emissions
1971	33.3	2.8%
1972	34.1	2.7%
1973	34.0	2.9%
1974	32.9	2.4%
1975	30.9	2.3%

Table 3 shows a breakdown of national hydrocarbon emissions for mobile and stationary sources and displays the emissions from cutbacks in context with the two other sources.

Table 3

U.S. Hydrocarbon Emissions by Category(9)
(10^6 tons/year)

	MOBILE SOURCES	STATIONARY SOURCES	CUTBACK SOURCES
1971	13.7	19.6	1.0
1972	14.0	20.1	.9
1973	13.7	20.3	1.0
1974	12.5	20.4	.8
1975	11.7	19.2	.7

Appendix C contains additional detailed information: Table C-1 summarizes annual national sales of cutback asphalts for paving purposes from 1971 through 1975; Table C-2 displays by EPA Region and by State, sales of cutback asphalts and sales of emulsified asphalts in 1975; and Table C-3 displays by EPA Region and by State the statewide hydrocarbon emissions from the use of cutback asphalts, State total hydrocarbon emissions, and the percentage of State total emissions accounted for by the cutback asphalts.

It is further noted that some states experience frequent air mass stagnation and have oxidant air quality problems. Some of these states, e.g., Wisconsin, Indiana, Illinois, Ohio, Pennsylvania, Virginia and West Virginia, require regulatory control of HC emissions for attainment and maintenance of oxidant ambient air quality standards. These states also have significant quantities of hydrocarbon emissions attributable to paving with cutback asphalts.

V. Energy Conservation Considerations

In 1975, 10,249,250 barrels of petroleum diluents were used to liquify asphalt for road paving operations. This amount of cutback is equivalent to 464,906,000 gallons of gasoline, enough to fuel almost 558,000 automobiles for a single year in the United States. Rather than powering automobiles, airplanes, or industry, however, energy in the form of diluents was poured onto road surfaces, where some evaporated and some remains. The energy impact of using cutback asphalts is just as striking when viewed in terms of the energy expended per gallon of paving material. The total energy associated with manufacturing, processing, and laying one gallon of cutback asphalt is about 50,200 Btu. On the other hand, analysis of emulsified asphalts shows that about 98% of the petroleum diluents is replaced with water with the result that only about 2,830 Btu is associated with each gallon of paving material. The components of these energy costs are described in Appendix D.

VI. Eight-State Survey of Paving Practices and Economic Considerations

State highway maintenance divisions in eight states were contacted for information, opinions, and experiences regarding the use of emulsified asphalt paving materials. The states selected for this survey were the larger users of asphalt. Since each state is responsible for some fraction (which may differ for each state) of the roads within its boundaries, this survey addresses only those asphalt paving operations for which the state is directly responsible.

In general, the survey showed that there has been an increased use of emulsified asphalts. This increased use, which varies with each state contacted, has been brought about primarily through fuel conservation measures and economic considerations. Relatively little consideration is given to HC emission from paving operations. For example, in Allegheny County, Pa., the Pennsylvania DOT uses emulsified asphalts almost exclusively for county road paving operations because of conservation and economics. In areas where such considerations do not exist, the choice of emulsified asphalt or cutback asphalt depends largely upon user preference as well as experience in specific materials and suppliers.

Individual responses ranged from general acceptance of emulsified asphalts for paving to indifference and skepticism about emulsions. Pennsylvania has changed from 30% emulsions/70% cutbacks in 1973 to 70% emulsions/30% cutbacks today. New York State uses 97% emulsions/ 3% cutbacks.

New York and Pennsylvania have initiated training programs to instruct their personnel and contractor personnel in the correct use of emulsions.

Appendix D details further energy conservation considerations.

VII. Summary and Conclusions

The air quality and energy conservation aspects of the use of liquified asphalt for paving operations have been analyzed to determine the potentials for energy savings and reduced emissions. Cutback asphalts are liquified with hydrocarbon distillates such as kerosene or naphtha; these reactive hydrocarbons are emitted during the curing process. Emulsified asphalts use water and an emulsifying agent for liquifaction; virtually no pollutants are emitted during the curing of emulsions.

Overall, more than 10,000,000 barrels of distillates are used annually for paving purposes. Most of this is evaporated into the atmosphere; the remainder is retained in the pavement. Use of emulsions would save almost all of those 10,000,000 barrels of distillates for use as or conversion to fuels.

In some states the curing of cutback asphalts accounted for a significant amount of the state's total annual hydrocarbon emissions. This problem is made more serious by the fact that asphalt paving operations take place primarily during warm weather when oxidant formation from the photochemical synthesis of hydrocarbon emissions is most likely. Reduced use of cutback asphalts could decrease materially the oxidant problem in these states.

It is anticipated that a minimal amount of cutback asphalt will continue to be used at temperatures lower than 50°F and for dusty surfaces. Also, some cutbacks will be used where portable plants are not available, because the four week stockpile life of emulsions is a problem. Other concerns with traffic control, rolling, aggregate selection and application, emulsion selection, etc., (discussed in Appendix B), can usually be met through good management.

Significant energy savings and air quality improvements can be realized from the increased use of emulsified asphalts.

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Appendix A

Commonly Used Terms Associated with Asphalt Paving Operations

1. Crack Filler - Asphalt used to fill and seal cracks in existing pavements.
2. Dust Palliative - A light application of liquified asphalt (cutback or emulsified asphalt) for the express purpose of controlling loose dust.
3. Maintenance Mix - A mixture of asphalt and mineral aggregate for patching holes, depressions, and distressed areas in existing pavements. These mixes are suitable for relatively small spot application, hot or at ambient temperature, using hand-laying and compaction techniques. This includes mixes for immediate use or for stockpiling for future use.
4. Penetration Macadam - Pavement construction using essentially one-size coarse aggregate that is penetrated in place by an application of asphalt binder. The asphalt application may be followed by an application of finer aggregate to reduce the void space.
5. Plant Mix, Cold Laid - A mixture of liquified asphalt (cutback or emulsified asphalt) and mineral aggregate prepared in a central bituminous mixing plant and spread and compacted at the job site when the mixture is at or near ambient temperature.
6. Plant Mix, Hot Mix - Hot Laid - A mixture of asphalt and mineral aggregate usually prepared in a conventional hot-mix plant or drum mixer at a temperature of about 250°F and spread and compacted at the job site at a temperature above 200°F.

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7. Prime Coat - An application of asphalt to an absorptive surface to penetrate and bind the aggregate surface and promote adhesion between it and the new superimposed construction.

8. Road Mix (Mix-In-Place) and Travel Plant Mix - A procedure by which the asphalt and mineral aggregate are mixed on the job site by means of travel mixers, motor graders, or other special road-mixing equipment.

9. Surface Treatment - An asphalt surface that results from one or more successive alternate applications of asphalt binder and cover aggregate to a prepared consolidated gravel, crushed stone, waterbound macadam, earth, stabilized soil, or similar base. Multiple application of asphalt and mineral aggregates may be used.

10. Seal Coat - An asphalt surface that results from one or more successive alternate applications of asphalt binder and cover aggregate to an existing paved surface.

11. Slurry Seal - A uniform application of a mixture of emulsified asphalt, fine aggregate, mineral filler, and water to an existing pavement. Single or multiple applications may be used.

12. Tack Coat - An application of asphalt applied to an existing surface to provide a bond between new surfacing and existing surface and to eliminate slippage planes where the new and existing surfaces meet.

Appendix B

Pros and Cons - Emulsified Asphalts

In any comparison of alternate methods for accomplishing a given job there is usually a concern for the advantages and disadvantages of one method relative to another. In the evaluation of emulsified asphalts versus cutback asphalts, such concerns were raised and have been considered. Reduced hydrocarbon emissions and fuel conservation have been cited as advantages to be expected from the use of emulsified asphalts instead of cutback asphalts. The reduction in emissions and the fuel savings are significant. Cost comparisons are generally favorable to emulsified asphalts but there are specific instances where the cost differential is negligibly small. While the foregoing suggests that the large-scale use of emulsified asphalts should be encouraged, there are a number of reasons which prevent a complete switchover to emulsified asphalts. Some of the reasons are intrinsic to the use of emulsions; the other reasons or objections follow from local practices. There is little we can do about the intrinsic reasons in the short term; research and development, however, may remove these reasons in the long run. Reasons or objections based upon local practices are usually amenable to change. In the following, both kinds of reasons are considered.

Intrinsic reasons which stand in the way of universal acceptance of emulsified asphalts include: 1) the time required for the water to evaporate. This means that a newly paved road should be closed to traffic

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upwards of two hours to allow the asphalt to set up. Under unfavorable conditions (high humidity, calm air, temperatures lower than 50°-60°F. this could extend to a day or more. 2) the surface to be paved should be swept clean of dust. This means also that the aggregate should be free of dust which passes through a #200 sieve. Dust causes the emulsion to break prematurely, that is, to accelerate the separation of the asphalt and the water.

The second class of reasons for not using emulsified asphalts can be regarded as non-intrinsic since there are ways of meeting these objections. These include: 1) a stockpile life of only four weeks. (Cutback asphalts have a long stockpile life). Use of portable mixing plants should overcome this objection. 2) Possible washout in a heavy rain. Care should be taken not to use emulsified asphalts when rain threatens. 3) "It's not like buying an 'off-the-shelf' item." Cooperation between the contractor, aggregate supplier, and emulsion supplier should result in the proper selection of an emulsified asphalt. 4) Miscellaneous reasons which can be met through the implementation of a training program to instruct contractors and operators in the proper use of emulsified asphalts.

In summary, emulsified asphalts cannot be used at temperatures lower than 50° and they cannot be used on dusty surfaces. Where portable plants are not available, the four week stockpile life is a problem. Traffic control is more critical than for cutback asphalt paved roads. Other concerns, such as rolling, aggregate selection and application, emulsion selection, etc. can usually be met through good engineering and construction practices.

Some comments by FHWA follow:

"In some States, maintenance materials may be purchased on annual contracts. This may create ideal conditions for the use of emulsions since the available expertise of the emulsion manufacturer can be utilized to insure a satisfactory product by adjusting the emulsion formulation to suit the aggregates, designing the mixture and training personnel. In the competitive bidding situation for construction projects this may not be the case. Traditionally, State's material sections have either designed the bituminous mixtures or verified the contractor's submitted mix design for adequacy to the intended purpose. A number of the States have had little or no experience in the design of asphalt emulsion mixtures and currently there are no nationally recognized standard procedures for the laboratory design of these mixtures as there is for hot asphaltic concrete or cutback asphalt mixes. A large research effort is necessary in this area."

"It can be safely said that all of the State highway agencies are aware of and concerned with the needs for energy conservation and protection of the environment. The slower than desired trend by some of these agencies toward total substitution of emulsions for cutbacks can in part be attributed to the following factors.

1. Lack of nationally accepted standard laboratory design procedures for asphalt emulsion mixtures. A number of design methods have been developed, mostly by members of the emulsion manufacturing industry. None of these have been endorsed by the standardizing associations AASHTO or ASTM. The availability of a recognized objective reproducible

laboratory design procedure for use by the highway agencies is considered a necessity in the effort to foster greater usage of asphalt emulsions.

2. Lack of reliable data on the structural worth of the asphalt emulsion mix. The pavement designer needs this information in the development of the structural section for a project. The general use of emulsions in the past has not been conducive to obtaining this type of data.

3. The tight money conditions that most State highway agencies have experienced in the past 3 years. This has not enhanced the climate for highway agencies to more or less experiment with a new product particularly when there is no price advantage. In response to item 1 above, the FHWA's Office of Research and Development has underway an in-house effort to develop a laboratory method of asphalt emulsion mix design. However, the allocation of necessary manpower and financial resources has been somewhat limited because of competing research requirements. That is not to say that we believe the effort to be unwarranted, just that strictly from a highway point of view there are other, more urgent, research needs."

Appendix C

Liquified Asphalt Data: Sales, Hydrocarbon Emissions Estimates - National and State Summaries

Table 4 displays a summary of national sales of cutback asphalt for paving purposes. It is based on Bureau of Mines annual reports of asphalt sales for the years shown. The Bureau of Mines data is further broken down into the three categories of cutbacks based on an estimated usage ratio of 65% Medium Cure (MC) and 35% Rapid Cure (RC).(8)

Table C-1

Summary of National Sales of Cutback Asphalts for Paving

(tons/year)

Year	Slow Cure (Road Oils)	Medium Cure	Rapid Cure	Total
1971	1,543,091	2,557,868	1,375,775	5,476,734
1972	1,370,546	2,509,061	1,351,033	5,230,640
1973	1,424,000	2,743,095	1,477,051	5,644,146
1974	1,251,091	2,183,205	1,175,572	4,609,868
1975	991,455	2,020,359	1,087,886	4,099,700

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Table C-2 Sales of Cutback Asphalt and Emulsified Asphalt in 1975, by EPA Region and State

EPA Region and State	Cutback Asphalt Sales (Includes Road Oils) (tons)	Emulsified Asphalt Sales (tons)
Region I		
Connecticut	20,355	2,340
Maine	23,702	16,742
Massachusetts	18,510	4,855
New Hampshire	22,982	12,994
Rhode Island	927	677
Vermont	321	299
Region II		
New Jersey	26,528	55,357
New York	103,435	156,755
Region III		
Delaware	1,168	1,746
Maryland + D.C.	42,411	62,122
Pennsylvania	143,096	57,369
Virginia	58,222	58,270
West Virginia	11,707	31,238
Region IV		
Alabama	45,138	51,829
Florida	46,387	26,753
Georgia	50,003	56,318
Mississippi	2,989	27,658
Kentucky	37,241	71,455
North Carolina	31,966	80,631
South Carolina	16,993	47,514
Tennessee	25,651	112,447
Region V		
Illinois	312,041	31,042
Minnesota	129,783	17,815
Michigan	39,305	24,441
Ohio	297,417	182,896
Indiana	80,805	162,636
Wisconsin	125,093	16,853

Region VI		
Arkansas	68,829	40,454
Louisiana	19,867	35,631
New Mexico	70,848	40,228
Oklahoma	390,836	7,372
Texas	189,648	131,079
Region VII		
Iowa	98,242	17,496
Kansas	121,111	38,427
Missouri	470,686	13,102
Nebraska	21,928	8,519
Region VIII		
Colorado	73,736	1,255
Montana	50,692	6,099
North Dakota	49,373	22,140
South Dakota	41,152	5,771
Utah	27,397	17,006
Wyoming	15,705	1,931
Region IX		
Arizona	152,121	100,987
California	236,685	136,802
Hawaii	5,220	- -
Nevada	47,183	6,828
Region X		
Alaska	7,416	5,370
Idaho	60,426	21,008
Oregon	25,417	58,074
Washington	141,066	57,246
Total	4,099,700	2,143,877

Table C-3
Cutback Asphalt Hydrocarbon Emissions Contribution to State Total Hydrocarbon Emissions[10,11]

EPA Region and State	Cutback Asphalt HC Emissions Total* and % of State HC Emissions[3] (tons)		State Total HC Emissions[11] ** (tons)
Region I			
Connecticut	4,286	1.9%	221,736
Maine	4,991	3.8%	125,390
Massachusetts	3,897	<1%	520,930
New Hampshire	4,838	5.2%	88,366
Rhode Island	196	<1%	85,283
Vermont	69	<1%	41,372
Region II			
New Jersey	5,586	<1%	639,325
New York	21,532	1.9%	1,116,330
Region III			
Delaware	247	<1%	64,813
Maryland & D.C.	8,930	2%	427,337
Pennsylvania	30,128	3.6%	811,992
Virginia	12,259	2.4%	483,501
West Virginia	2,449	2.1%	113,711
Region IV			
Alabama	8,346	1.1%	729,076
Florida	16,175	1.4%	1,140,776
Georgia	10,524	2.2%	467,461
Mississippi	370	<1%	224,298
Kentucky	6,781	1.9%	352,382
North Carolina	6,730	1.2%	548,584
South Carolina	3,578	<1%	360,971
Tennessee	4,670	1.1%	391,719

Region V			
Illinois	56,814	3%	1,831,465
Minnesota	23,627	5.8%	381,938
Michigan	7,157	<1%	824,898
Ohio	55,145	4.7%	1,117,174
Indiana	14,712	2.4%	603,771
Wisconsin	18,770	3.2%	574,454
Region VI			
Arkansas	12,726	6.3%	189,896
Louisiana	3,673	<1%	1,228,769
New Mexico	13,098	8.4%	143,116
Oklahoma	72,462	15.6%	391,672
Texas	35,281	1.6%	2,211,509
Region VII			
Iowa	17,888	4.8%	353,844
Kansas	22,051	6.2%	336,756
Missouri	87,270	16.3%	448,299
Nebraska	8,023	2.1%	378,922
Region VIII			
Colorado	12,857	5.4%	224,797
Montana	8,839	4.3%	197,518
North Dakota	9,127	11.3%	71,522
South Dakota	5,059	5.6%	85,161
Utah	4,778	4.4%	103,047
Wyoming	2,739	3.9%	67,654
Region IX			
Arizona	23,577	8.9%	241,985
California	33,799	1.6%	2,115,039
Hawaii	771	<1%	94,405
Nevada	7,006	11.6%	53,429

Region X

Alaska	1,095	<1%	109,370
Idaho	10,536	8.2%	118,532
Oregon	3,753	1.3%	290,495
Washington	20,823	5.8%	336,944

*Weighted average by state. See Table 1 narrative (Sect IV, p.5)

**State total hydrocarbon emissions estimates are based upon latest available data on emission sources. All hydrocarbons are included. Asphalt paving operations were not included as a source.

Appendix D

Energy Conservation Considerations

The energy associated with cutback asphalt can be compared with that associated with emulsified asphalt by considering their respective compositions, the attendant process energy, and the energy required for asphalt spray applications using an asphalt distributor. Since the petroleum distillates content of cutback asphalt varies from 20% to 50% of the total mixture, the energy associated with these asphalts spans a wide range. In order to strike one kind of comparison, consider cutback asphalt and emulsified asphalt, each with 65% asphalt. This is reasonable because this percentage is generally recommended for emulsified asphalts and the eight-state survey (Section VI and Appendix E) revealed that the amount of cutback asphalt (typically containing 60% - 70% asphalt) required for paving operations was about the same as for emulsified asphalts. About 2500 Btu is required to process a gallon of asphalt for paving(17) and to this is added the energy content of the cutback which, for a medium cure is about 135,000 Btu/gal. Thus, for one gallon of cutback asphalt with 65% asphalt and 35% cutback the energy represented therein is 2500 + .35 x 135,000 = 49,750 Btu. About 2050 Btu is required to obtain one gallon of emulsified asphalt, independent of emulsifier energy content.(17) According to ARMAK (leading manufacturer of emulsifiers) there is about 7500 Btu/lb associated with the production of emulsifiers. At about 0.084 lb emulsifier/gal (1%) an additional 630 Btu should be added to the 2050 Btu for each gallon of emulsified asphalt giving an intermediate total of 2680 Btu/gal.

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Finally, the energy requirements for asphalt spray applications using an asphalt distributor amount to 444 Btu/gal for cutbacks and 144 Btu/gal for emulsions.(17) (An additional 300 Btu/gal is required to heat the cutback asphalt). Hence, the total energy associated with laying one gallon of cutback asphalt is about 50,200 Btu while the total energy associated with a gallon of emulsified asphalt is about 2830 Btu.

Each ton of petroleum diluent used in cutbacks is equivalent to about 300 gallons.(3) The tons of volatile diluents displayed in Table 1 convert to barrels (42 gals/bbl) as follows:

Table D-1

Petroleum Diluents Used to Liquify Asphalt
(Estimated Bbls/year)

1971	13,691,836
1972	13,076,600
1973	14,110,364
1974	11,524,671
1975	10,249,250

These petroleum diluents (fuels) were evaporated to the atmosphere or were retained in the asphalt pavement. In terms of energy content, the amount of gasoline equivalent to the 10,249,250 barrels of petroleum diluents used in 1975 for cutback asphalts is:

$$(10{,}249{,}250 \text{ bbl}) \times (42 \text{ gal/bbl}) \times \frac{135{,}000 \text{ Btu/gal diluent}}{125{,}000 \text{ Btu/gal gasoline}} =$$

464,906,000 gal gasoline

For an annual mileage of 10,000 at 12 mpg this gasoline equivalent would fuel almost 558,000 automobiles for one year.

Appendix E

Eight-State Survey of Paving Practices and Economic Considerations

Eight state highway maintenance divisions were contacted for their opinions, facts, and experiences regarding the use of emulsified asphalt paving materials. The states selected were the larger users of asphalt. An initial contact with each state was made in order to establish an overview of their operations. A second contact was made to obtain more detailed information.

In discussions with the eight states it was found that there was an insignificant difference (overall) in the costs of the two types of asphalts at this time. Until three years ago the cutback asphalts were less expensive but the increase in oil prices has changed this picture.

The local picture may be influenced by varying economic considerations. However, the availability of light diluents from a nearby (and older) refinery could make cutbacks very attractive. Newer refineries are able to recycle naphtha and similar light stock to turn out a more profitable product. When a nearby source of these light diluents is not available, the additional freight costs to deliver the material usually tips the scales in favor of emulsions.

A specific example is found in Waukesha County, Wisconsin.(15) The switch to emulsions was made to conserve energy in 1973. In 1976 the county used emulsions for resurfacing and realized about a 10% cost saving in materials: 36.92¢/gal. for cutback vs. 33.75¢/gal. for emulsions.

The following is an account of discussions with each highway maintenance division.

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Illinois

Primary roads are usually paved with portland cement concrete. Maintenance operations and paving of secondary roads are under local (city or county) jurisdiction. The local agencies are being encouraged ("jawboned") to use emulsified asphalts. The state "Specification Book" now lists emulsions as a viable option. Cationic and High Float Emulsions (HFE) are preferred (for definitions see reference 2). Stockpile life is no problem. There is almost no cost differential. Most user problems are expected to be resolved as more plants come into operation. Also, the expanded use of "porta-pugs" (portable on-site mixing equipment) should benefit pre-mix emulsions.

Paving with emulsions is not done after September 30. Under favorable conditions (3 consecutive preceding days with maximum temperatures over 60°F in the shade and a night time minimum of 40°F or higher) emulsified asphalts can be used until October 31. Use of emulsions is resumed in the spring when these temperature ranges are obtained.

Missouri

Until 3 or 4 years ago cutback asphalt was used exclusively. Today, emulsions are satisfactory for seal coats, priming, and in mixtures for base construction. Emulsions are generally unsatisfactory for road surfaces. The emulsified asphalt industry in Missouri is in its infancy and has not been able to live up to its claims.

Problems include emulsions break-up and non-adherence to aggregate resulting in rough surface. Procurement of emulsion asphalt is not like buying an off-the-shelf item. The emulsifying agent and proportions must be tailored to the available aggregate the particular job. Their most successful emulsions use 4-10% cutback.

Most of the paving work is done under contract.

Pennsylvania

The Department of Transportation has its own environmental section which maintains liaison with the state Department of Environmental Resources.

The expanded use of emulsified asphalts was initiated as a fuel and cost conservation measure about three years ago. DOT has continued to use emulsions because they expect the cost of petroleum diluents to increase further. Pennsylvania is directly responsible for and controls must of its highway system (as do Virginia, North Carolina, and Texas), i.e., 45% of the 20,000 miles of roads in the state. The Pennsylvania DOT is under annual contracts with asphalt suppliers and hence control the type of asphalt to used on a given job.

About ten years ago emulsified asphalts were used for the first time. Three years ago usage was 30% emulsions. Today, it is 70% emulsions. No further increase is expected. The state is committed to emulsions and has directed its districts accordingly. One-day training programs have been set up for administrators as well as operators.

Hot-mix will be used for primary roads for some time because suppliers have considerable investment in plants and equipment.

Special mixtures are required for emulsion asphalts which are to be stockpiled. This operation demands tough quality control and requires dry stone (which retards curing) and the right temperature. Further, the mixture cannot exceed a depth of 8 feet. Pennsylvania also uses Travel-mix plants to prepare the emulsion at the job site.

- Emulsions are used for recycling pavements. Cutbacks are still used for dust control.

Ohio

The increased use of emulsions is being encouraged. The state cannot, however, mandate to the local governments. At present there is an insignificant price differential but the cost of cutback asphalt is expected to increase.

Oklahoma

Emulsified asphalts are used for seal coats and slurry seals - about 10-15% more emulsified asphalt is required than cutback asphalt for a given surfacing requirement. Emulsions are not used for surface paving. There is an insignificant price differential today. Emulsion costs are expected to decrease but a trend to increased use of emulsions is not foreseen.

Texas

The state is trying to increase use of emulsions as a result of energy conservation efforts and financial conditions. Overall they find an economic advantage in the use of emulsions. Emulsions are not used for heavy traffic applications or where roads must be opened immediately after re-surfacing. Stockpile life for emulsions is about one month.

There are 25 Districts in Texas and each District Engineer is responsible for maintenance. Attitudes are important - some users have been using emulsions with success for years while others are unalterably opposed to it.

New York

In 1976, 97% of liquid asphalts used were emulsions; 3% were cutbacks. New York state has an educational program to instruct its personnel in the correct use of emulsions and recommends and stresses the advantages of emulsions over cutbacks. In 1977 the use of cutbacks will be restricted to pavement repairs only. The state knows that emulsions are actually being used in paving operations by inspecting and testing material for acceptance and adherence to specifications. They have experienced no stockpile problems. They feel that four weeks is a good average for stockpile life and generally use the material within a four week period. Some material has been stockpiled for longer periods with no problems. The foregoing information pertains only to the use of emulsions by the New York State Department of Transportation and does not include counties and municipalities within the state.

California

California State Department of Transportation uses cutbacks as the primary liquid asphalt. The emulsion that is used is mainly for seal costs. They have no prejudice against emulsions per se, but they stockpile for the whole winter, particularly for the remote areas in the northern part of the state, and emulsified asphalt stockpiles just will not last more than a few weeks before they set up and become unusable. The cost differential between emulsions and cutbacks is negligible. Paving operations are in compliance with environmental requirements.

Although not a part of the eight-state survey, a discussion with the Southern California Air Pollution Control District, Metropolitan Zone (formerly L.A. District) is believed pertinent. Cutbacks are forbidden to be used in that District under the Volatiles Rules, Rule 442 (Usage of Solvents) and Rule 443 (Labeling of Solvents). These rules are formerly known as Rule 66.